Appendix G

Air Quality

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APPENDIX G. AIR QUALITY

Potential releases of nonradiological and radiological pollutants associated with the construction, operation and monitoring, and closure of the proposed Yucca Mountain Repository could affect the air quality in the surrounding region. This appendix discusses the methods and additional data and intermediate results that the U.S. Department of Energy (DOE) used to estimate impacts from potential releases to air. Results for the Proposed Action are presented in Chapter 4, Section 4.1.2, and in Chapter 8, Section 8.2.2 for Inventory Modules 1 and 2.

Nonradiological pollutants can be categorized as hazardous and toxic air pollutants, criteria pollutants, or other substances of particular interest. Repository activities would cause the release of no or very small quantities of hazardous and toxic pollutants; therefore, these pollutants were not considered in the analysis. Concentrations of six criteria pollutants are regulated under the National Ambient Air Quality Standards (40 CFR Part 50) established by the Clean Air Act. This analysis evaluated releases and potential impacts of four of these pollutants—carbon monoxide, nitrogen dioxide, sulfur dioxide, and particulate matter with an aerodynamic diameter of 10 micrometers or less (PM_{10})—quantitatively. It also considered the two other criteria pollutants—lead and ozone—and particulate matter with an aerodynamic diameter of 2.5 micrometers or less ($PM_{2.5}$), a new limit, which has not yet been implemented. In addition, this analysis considers potential releases to air of cristobalite, a form of crystalline silica that can cause silicosis and is a potential carcinogen. These pollutants could be released during all project phases. Section G.1 describes the methods DOE used to calculate impacts from releases of criteria pollutants and cristobalite.

Radionuclides that repository-related activities could release to the atmosphere include the noble gas krypton-85 from spent nuclear fuel handling during the operation and monitoring phase, and naturally occurring radon-222 and its decay products from ventilation of the subsurface facility during all project phases. Other radionuclides would not be released or would be released in such small quantities they would result in very small impacts to air quality. Such radionuclides are not discussed further in this appendix. Section G.2 describes the methods DOE used to calculate impacts of radionuclide releases.

G.1 Nonradiological Air Quality

This section describes the methods DOE used to analyze potential impacts to air quality at the proposed Yucca Mountain Repository from releases of nonradiological air pollutants during the construction, operation and monitoring, and closure phases, and a retrieval scenario. It also describes intermediate results for various repository activities. Table G-1 lists the six criteria pollutants regulated under the National Ambient Air Quality Standards or the Nevada Administrative Code along with their regulatory limits and the periods over which pollutant concentrations are averaged. The criteria pollutants addressed quantitatively in this section are nitrogen dioxide, sulfur dioxide, particulate matter 10 micrometers or less in aerodynamic diameter (PM_{10}), and carbon monoxide. No sources of airborne lead would occur at the repository, so evaluations and results are not presented. Particulate matter 2.5 micrometers or less in aerodynamic diameter ($PM_{2.5}$) and ozone are discussed below, as is cristobalite, a mineral occurring naturally in the subsurface rock at Yucca Mountain.

The purpose of the ozone standard is to control the ambient concentration of ground-level ozone, not naturally occurring ozone in the upper atmosphere. Ozone is not emitted directly into the air; rather, it is formed when volatile organic compounds react in the presence of sunlight. Nitrogen dioxides are also important precursors to ozone. Small quantities of volatile organic compounds would be released from repository activities; the peak annual release would be about 700 kilograms (1,500 pounds) (DIRS 152010-CRWMS M&O 2000, Table 6-2, p. 52). Because Yucca Mountain is in an attainment area for ozone, the analysis compared the estimated annual release to the Prevention of Significant Deterioration

Table G-1. Criteria pollutants and regulatory limits.

Pollutant	Period	Regulatory limit[a] Parts per million	Regulatory limit[a] Micrograms per cubic meter
Nitrogen dioxide	Annual	0.053	100
Sulfur dioxide	Annual	0.03	80
	24-hour	0.14	365
	3-hour	0.50	1,300
Carbon monoxide	8-hour	9	10,000
	1-hour	35	40,000
PM_{10}	Annual		50
	24-hour		150
$PM_{2.5}$[b]	Annual		15
	24-hour		65
Ozone	8-hour	0.08	157
	1-hour	0.12	235
Lead	Quarterly		1.5

a. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391. Not all limits are provided in parts per million.

b. Standard not yet implemented.

of Air Quality emission threshold for volatile organic compounds from stationary sources (40 CFR 52.21). The volatile organic compound emission threshold is 35,000 kilograms (77,000 pounds) per year, so the peak annual release from the repository would be well below this level. Accordingly, the analysis did not address volatile organic compounds and ozone further, although this does not preclude future, more detailed analyses if estimates of volatile organic compound emissions change.

The U.S. Environmental Protection Agency revised the primary and secondary standards for particulate matter in 1997 (62 *FR* 38652, July 18, 1997), establishing annual and 24-hour $PM_{2.5}$ standards at 15 micrograms per cubic meter and 65 micrograms per cubic meter, respectively. Primary standards set limits to protect public health, including the health of “sensitive” populations. Secondary standards set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings. Because the new particulate standard will regulate $PM_{2.5}$ for the first time, the agency has allowed 5 years for the creation of a national monitoring network and the analysis of collected data to help develop state implementation plans. The new $PM_{2.5}$ standards have not been implemented and the imposition of local area controls will not be required until 2005. By definition, $PM_{2.5}$ levels can be no more than, and in the real world are always substantially less than, PM_{10} levels. In general, $PM_{2.5}$ levels would be approximately one-third of the PM_{10} levels. As the analysis for PM_{10} shows, even the maximum PM_{10} levels that could be generated by the Proposed Action are substantially below the $PM_{2.5}$ standards. Thus, although no detailed $PM_{2.5}$ analysis has been conducted, the PM_{10} analysis can be regarded as a surrogate for a $PM_{2.5}$ analysis and illustrates that potential $PM_{2.5}$ levels would be well below applicable regulatory standards.

Cristobalite, one of several naturally occurring crystalline forms of silica (silicon dioxide), is a major mineral constituent of Yucca Mountain tuffs (DIRS 104523-CRWMS M&O 1999, p. 4-81). Prolonged high exposure to crystalline silica can cause silicosis, a disease characterized by scarring of lung tissue. An increased cancer risk to humans who already have developed adverse noncancer effects from silicosis has been shown, but the cancer risk to otherwise healthy individuals is not clear (DIRS 103243-EPA 1996, p. 1-5). Cristobalite is principally a concern for involved workers because it could be inhaled during subsurface excavation operations. Appendix F, Section F.1.2, contains additional information on crystalline silica.

While there are no limits for exposure of the general public to cristobalite, there are limits to workers for exposure (29 CFR 1910.1000). Therefore, this analysis used a comparative benchmark of 10 micrograms per cubic meter, based on a cumulative lifetime exposure of 1,000 micrograms per cubic meter multiplied by years (that is, the average annual exposure concentration times the number of years exposed). At this level, an Environmental Protection Agency health assessment (DIRS 103243-EPA 1996, pp. 1-5 and 7-5) states that there is a less than 1-percent chance of silicosis. Over a 70-year lifetime, this cumulative exposure benchmark would correspond to an annual average exposure concentration of about 14 micrograms per cubic meter, which was rounded down to 10 micrograms per cubic meter to establish the benchmark.

Cristobalite would be emitted from the subsurface in exhaust ventilation air during excavation operations and would be released as fugitive dust from the excavated rock pile, so members of the public and noninvolved workers could be exposed. Fugitive dust from the excavated rock pile would be the largest potential source of cristobalite exposure to the public. The analysis assumed that 28 percent of the fugitive dust released from this rock pile and from subsurface excavation would be cristobalite, reflecting the cristobalite content of the parent rock, which ranges from 18 to 28 percent (DIRS 104523-CRWMS M&O 1999, p. 4-81). Using the parent rock percentage probably overestimated the airborne cristobalite concentration, because studies of both ambient and occupational airborne crystalline silica have shown that most of this airborne material is coarse and not respirable and that larger particles deposit rapidly on the surface (DIRS 103243-EPA 1996, p. 3-26).

G.1.1 COMPUTER MODELING AND ANALYSIS

DOE used the Industrial Source Complex computer program to estimate the annual and short-term (24-hour or less) air quality impacts at the proposed Yucca Mountain Repository. The Department has used this program in recent EISs (DIRS 101802-DOE 1995, all; DIRS 101814-DOE 1997, all; DIRS 101816-DOE 1997, all) to estimate nonradiological air quality impacts. The program contains both a short-term model (which uses hourly meteorological data) and a long-term model (which uses joint frequency meteorological data). The program uses steady-state Gaussian plume models to estimate pollutant concentrations from a variety of sources associated with industrial complexes (DIRS 103242-EPA 1995, all). This modeling approach assumes that (1) the time-averaged pollutant concentration profiles at any distance downwind of the release point may be represented by a Gaussian (normal) distribution in both the horizontal and vertical directions; and (2) the meteorological conditions are constant (persistent) over the time of transport from source to receptor. The Industrial Source Complex program is appropriate for either flat or rolling terrain, and for either urban or rural environments. The Environmental Protection Agency has approved this program for specific regulatory applications. Input requirements for the program include source configuration and pollutant emission parameters. The short-term model was used in this analysis to estimate all nonradiological air quality impacts and uses hourly meteorological data that include wind speed, wind direction, and stability class to compute pollutant transport and dispersion.

Because the short-term pollutant concentrations were based on annual usage or release parameters, conversion of annual parameter values to short-term values depended on the duration of the activity. Many of the repository activities were assumed to have a schedule of 250 working days per year, so the daily release would be the annual value divided by 250.

In many cases, site- or activity-specific information was not available for estimating pollutant emissions at the Yucca Mountain site. In these cases, generic information was used and conservative assumptions were made that tended to overestimate actual air concentrations.

As noted in Section G.1, the total nonradiological air quality impacts are described in Chapter 4, Section 4.1.2, for the Proposed Action and in Chapter 8, Section 8.2.2, for the inventory modules. These impacts are the sum of air quality impacts from individual sources and activities that take place during each of the project phases and that are discussed later in this section (for example, dust emissions from the concrete batch facility during the construction phase). The maximum air quality impact (that is, air concentration) resulting from individual sources or activities could occur at different land withdrawal area boundary locations depending on the release period and the regulatory averaging time (see Section G.1.3). These maximums generally occur in a westerly or southerly direction. The total nonradiological air quality impacts presented in Sections 4.1.2 and 8.2.2 are the sum of the calculated maximum concentrations regardless of direction. Therefore, the values presented would be larger than the actual sum of the concentrations for a particular distance and direction. This approach was selected to simplify the presentation of air quality results.

G.1.2 LOCATIONS OF HYPOTHETICALLY EXPOSED INDIVIDUALS

The location of the public maximally exposed individual was determined by calculating the maximum ground-level pollutant concentrations. Because unrestricted public access would be limited to the site boundary, the analysis assumed that a hypothetical individual would be present at one point on the site boundary during the entire averaging time of the regulatory limit (Table G-1).

Table G-2 lists the distances from the North and South Portals to the land withdrawal area boundary where maximally exposed individual locations were evaluated. The table does not list all directions because the land withdrawal area boundaries would not be accessible to members of the public in some directions (restricted access areas of the Nevada Test Site and Nellis Air Force Range). The distance to the nearest unrestricted public access in these directions would be so large that there would be no air quality impacts. For the east to south-southeast directions, the distances to the land withdrawal area boundary would be large, but the terrain is such that plumes traveling in these directions tend to enter Fortymile Wash and turn south. The southern land withdrawal area boundary would be the location of a maximally exposed individual with long-term (1-year) unrestricted access, such as a resident. The short-term (1 to 24 hours) maximally exposed individual location would be the western land withdrawal area boundary, where an individual such as a hiker or hunter could be located. No long-term access (that is, residency) could occur at this location on government-owned land. The access periods evaluated are based on the exposure periods listed in Table G-1.

Table G-2. Distance to the nearest point of unrestricted public access (kilometers).[a,b,c]

Direction	From North Portal	From South Portal
Northwest	14	15
West-northwest	12	12
West	11	11
West-southwest	14	12
Southwest	18	16
South-southwest	23	19
South	21	18
South-southeast	21	19
Southeast	22	24

a. Source: Derived from (DIRS 104493-YMP 1997, all and DIRS 153849-DOE 2001, p. l-21)
b. Numbers are rounded to two significant figures.
c. To convert kilometers to miles, multiply by 0.62137.

G.1.3 METEOROLOGICAL DATA AND REFERENCE CONCENTRATIONS

DOE estimated the concentrations of criteria pollutants in the region of the repository by using the Industrial Source Complex program and site-specific meteorological data for 1993 to 1997 from air quality and meteorology monitoring Site 1 (DIRS 102877-CRWMS M&O 1999, electronic addendum). Site 1 is less than 1 kilometer (0.6 mile) south of the proposed North Portal surface facility location.

Similar topographic exposure leads to similar prevailing northerly and southerly winds at both locations. DOE used Site 1 data because an analysis of the data collected at all the sites showed that site to be most representative of the surface facilities (DIRS 102877-CRWMS M&O 1999, p. 7). Wind speed data are from the 10-meter (33-foot) level, as are atmospheric stability data, using the night-adjusted sigma-theta method (DIRS 101822-EPA 1987, pp. 6-20 to 6-32). Mixing height measurements were not available for Yucca Mountain so the analysis assumed a mixing height of approximately 140 meters (470 feet), which is one-tenth of the 1,420 meters (4,700 feet) mixing-layer depth for Desert Rock, Nevada. Desert Rock is the nearest upper air meteorological station, about 44 kilometers (27 miles) east-southeast near Mercury, Nevada. The average mixing height at Desert Rock was divided by 10 to simulate the mixing height during very stable conditions, which is when the highest concentrations from a ground-level source would normally occur. All nonradiological pollutant releases were assumed to come from ground-level point sources. Both of these conservative assumptions, made because of a lack of site-specific information, tend to overestimate actual air concentrations. Fugitive dust emissions could be modeled as an area source, but the distance from the source to the exposure location would be large [more than 10 kilometers (6 miles)] so a point source provides a good approximation. Some sources would have plume rise, such as boiler emissions, but this was not considered because there is inadequate information to characterize the rise.

The analysis estimated unit release concentrations at the land withdrawal area boundary points of maximum exposure for ground-level point-source releases. The concentrations were based on release rates of 1 gram (0.04 ounce) per second for each of the five regulatory limit averaging times (annual, 24-hour, 8-hour, 3-hour, or 1-hour). Various activities at the Yucca Mountain site could result in pollutants being released over four different periods in a 24-hour day [continuously, 8-hour, 12-hour (two 6-hour periods), or 3-hour]. Eleven combinations of release periods and regulatory limit averaging times would be applicable to activities at the Yucca Mountain site.

The analysis assumed that the 8-hour pollutant releases would occur from 8 a.m. to 4 p.m. and to be zero for all other hours of the day. Similarly, it assumed that the 3-hour releases would occur from 9 a.m. to 12 p.m. and to be zero for all other hours. The 12-hour release would occur over two 6-hour periods, assumed to be from 9 a.m. to 3 p.m. and from 5 p.m. to 11 p.m.; other hours would have zero release. Continuous releases would occur throughout the 24-hour day. The estimates of all annual-average concentrations assumed the releases were continuous over the year.

Table G-3 lists the maximum unit release concentrations for the 11 combinations of the Yucca Mountain site-specific release periods and regulatory limit averaging times. The analysis estimated the unit concentrations and directions using the meteorological data during a single year from 1993 through 1997 (DIRS 102877-CRWMS M&O 1999, electronic addendum) that would result in the highest unit concentration. For all years, the unit release concentrations for a particular averaging time are within a factor of 2 of each other. Table G-3 lists the 24-hour averaged concentration for the 3- and 12-hour release scenarios because the activities associated with these scenarios would only release PM_{10}, which has annual and 24-hour regulatory limits. The estimated concentration at the point of exposure was calculated by multiplying the estimated source release rate (presented for each source in the following sections) by the maximum unit release concentration for that averaging period.

Table G-3. Unit release concentrations (micrograms per cubic meter based on a release of 1 gram per second) and direction to maximally exposed individual location for 11 combinations of 4 release periods and 5 regulatory limit averaging times.[a]

	Direction from South Portal Development area	Unit release concentration	Direction from North Portal Operations Area	Unit release concentration
Continuous release – annual average concentration (1995)[b]				
	South-southeast	0.12	South-southeast	0.099
Continuous release – 24-hour average concentration (1993)				
	Southeast	1.0	West	0.95
Continuous release – 8-hour average concentration (1995)				
	Southeast	3.0	Southeast	2.5
Continuous release – 3-hour average concentration (1995)				
	West	6.1	West	6.1
Continuous release – 1-hour average concentration (1995)				
	West	18	West	18
8-hour release (8 a.m. to 4 p.m.) – 24-hour average concentration (1997)				
	West-southwest	0.19	West-northwest	0.18
8-hour release (8 a.m. to 4 p.m.) – 8-hour average concentration (1997)				
	West-southwest	0.57	West-northwest	0.52
8-hour release (8 a.m. to 4 p.m.) – 3-hour average concentration (1997)				
	West-southwest	1.5	West-northwest	1.4
8-hour release (8 a.m. to 4 p.m.) – 1-hour average concentration (1997)				
	West-northwest	3.3	West-northwest	3.3
12-hour release (9 a.m. to 3 p.m. and 5 p.m. to 11 p.m.) – 24-hour average concentration (1997)				
	West	0.95	West	0.95
3-hour release (9 a.m. to 12 p.m.) – 24-hour average concentration (1997)				
	West-northwest	0.17	West-northwest	0.17

a. Numbers are rounded to two significant figures.
b. Number in parentheses is the year from 1993 through 1997 for which meteorological data would result in the highest unit concentration.

G.1.4 CONSTRUCTION PHASE

This section describes the method used to estimate air quality impacts during the 5-year construction phase. DOE would complete the surface facilities during the construction phase, as well as sufficient excavation of the subsurface to support initial emplacement activities.

This analysis used calculations of the pollutant concentrations from various construction activities to determine air quality impacts. To calculate these impacts, estimated pollutant emission rates discussed in this section were multiplied by the unit release concentration (see Section G.1.3). This produced the pollutant concentration for comparison to regulatory limits. Short-term pollutant emission rates and concentrations were estimated using the method described in Section G.1.1.

The principal emission sources of particulates would be fugitive dust from construction activities on the surface, excavation of rock from the repository, storage of material on the excavated rock pile, and dust emissions from the concrete batch facility. The principal sources of nitrogen dioxide, sulfur dioxide, and carbon monoxide would be fuel combustion in trucks, cranes, and graders and emissions from a boiler in the South Portal Development Area. Nitrogen dioxide, sulfur dioxide, and carbon monoxide would also be emitted during maintenance of the excavated rock pile. The following sections describe these sources in more detail.

G.1.4.1 Fugitive Dust Emissions from Surface Construction

Fugitive dust would be generated during such construction activities as earth moving and truck traffic. All surface construction activities and associated fugitive dust releases were assumed to occur during 250 working days per year with one 8-hour shift per day. The preferred method suggested by the Environmental Protection Agency would be to break the construction activities into component activities (for example, earth moving, truck traffic) and calculate the emissions for each component. However, detailed information was not available for the construction phase, so a generic, conservative approach was taken. The release rate of total suspended particulates (particulates with aerodynamic diameters of 30 micrometers or less) was estimated as 0.27 kilogram per square meter (1.2 tons per acre) per month (DIRS 101824-EPA 1995, pp. 13.2.3-1 to 13.2.3-7). This estimated emission rate for total suspended particulates was based on measurements made during the construction of apartments and shopping centers.

The amount of PM_{10} (the pollutant of interest) emitted from the construction of the Yucca Mountain Repository probably would be less than 0.27 kilogram per square meter (1.2 tons per acre) per month because many of the particulates suspended during construction would be at the larger end of the 30-micrometer range and would tend to settle rapidly (DIRS 102180-Seinfeld 1986, pp. 26 to 31). Experiments on dust suspension due to construction found that at 50 meters (160 feet) downwind of the source, a maximum of 30 percent of the remaining suspended particulates at respirable height were in the PM_{10} range (DIRS 103678-Midwest Research Institute 1988, pp. 22 to 26). Based on this factor, only 30 percent of the 0.27 kilogram per square meter per month of total suspended particulates, or 0.081 kilogram per square meter (0.36 ton per acre) per month, would be emitted as PM_{10} from construction activities. Because the default emission rate was based on continuous emissions over 30 days, the daily PM_{10} emission rate would be 0.0027 kilogram per square meter (0.012 ton per acre) per day, or 0.00011 kilogram per square meter (0.00050 ton per acre) per hour. Dust suppression activities would reduce PM_{10} emissions; however, the analysis took no credit for normal dust suppression activities.

The estimation of the annual and 24-hour average PM_{10} emission rates required an estimate of the size of the area to be disturbed along with the unit area emission rate [0.00011 kilogram per square meter (0.00050 ton per acre) per hour] times 8 hours of construction per day. The analysis estimated that 20 percent of the total disturbed land area would be actively involved in construction activities at any given time. This was based on the total disturbed area at the end of the construction period divided by the number of years construction activities would last. Table G-4 lists the total areas of disturbance at various repository operation areas. The analysis assumed that the entire land area required for excavated rock storage (for both the construction phase and operation period) would be disturbed by excavated rock storage preparation activities, although only a portion of it would be used during the construction phase. Table G-5 lists fugitive dust emissions from surface construction; Table G-6 lists estimated air quality impacts from fugitive dust as the pollutant concentration in air and as the percent of the applicable regulatory limit.

Fugitive dust from construction would produce small offsite PM_{10} concentrations. The annual and 24-hour average concentrations of PM_{10} would be as high as 1.4 percent and about 3.3 percent, respectively, of the regulatory limit for the lower-temperature repository operating mode. The differences between the operating modes would be small; the lower-temperature repository operating mode would have the larger impacts due mainly to the area required for ventilation shafts, excavated rock storage, and aging pad construction, where used.

For Modules 1 and 2, the same technique was used as for the Proposed Action, but the amount of land disturbed would be larger than for the Proposed Action because of the need for more ventilation shafts and excavated rock storage. The increase in disturbed land area would increase the estimated air quality impacts. Higher-temperature repository operating mode impacts would be 1.2 percent (annual) and

2.8 percent (24-hour) of the regulatory limit. Lower-temperature repository operating mode impacts would be 1.2 to 1.7 percent (annual) and 2.9 to 4 percent (24-hour) of the regulatory limit.

Table G-4. Land area (square kilometers)[a] disturbed during the construction phase.[b]

	Operating mode	
Operations area	Higher-temperature	Lower-temperature
North Portal and roads	0.62	0.62
South Portal	0.15	0.15
Ventilation shafts and access roads	0.84	1 - 1.4
Total excavated rock storage	0.87	0.87 - 1.5
Landfill	0.04	0.04 - 0.061
Solar power generating station	0.22	0.22
Concrete batch plant	0.061	0.061
Concrete pads for aging	NA[c]	0 or 0.47[d]
Totals[e]	***2.8***	***3 - 4.5***
Area disturbed per year	0.55	0.6 - 0.83

a. To convert square kilometers to acres, multiply by 247.1.
b. Sources: DIRS 152010-CRWMS M&O (2000, p. 52); DIRS 150941-CRWMS M&O (2000, pp. 4-9 and 6-27); DIRS 150941-CRWMS M&O (2000, p. 1); DIRS 155515-Williams (2001, Part 1, pp. 27 and 29; Part 2, p. 18); DIRS 155516-Williams (2001, Item 1.5); DIRS 153882-Griffith (2001, p. 8).
c. NA = not applicable.
d. Applicable only for aging.
e. Numbers are rounded to two significant figures; therefore, totals might differ from sums of values.

Table G-5. Fugitive dust releases from surface construction (PM_{10}).[a]

Operating mode	Period	Pollutant emission (kilograms)[b]	Emission rate (grams per second)[c]
Higher-temperature	Annual	120,000	3.9
	24-hour	490	17[d]
Lower-temperature[e]	Annual	130,000 - 190,000	4.2 - 5.9
	24-hour	530 - 740	18 - 26[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on an 8-hour release period.
e. Range of values for lower-temperature operating mode.

Table G-6. Estimated fugitive dust air quality impacts (micrograms per cubic meter) from surface construction (PM_{10}).[a]

Operating mode	Period	Maximum concentration	Regulatory limit	Percent of limit
Higher-temperature	Annual	0.47	50	0.95
	24-hour	3.3	150	2.2
Lower-temperature	Annual	0.51 - 0.71	50	1 - 1.4
	24-hour	3.5 - 4.9	150	2.4 - 3.3

a. Numbers are rounded to two significant figures.

G.1.4.2 Fugitive Dust from Subsurface Excavation

Fugitive dust would be released during the excavation of rock from the repository. Subsurface excavation activities would take place 250 days per year in three 8-hour shifts per day. Excavation would generate dust in the tunnels, and some of the dust would be emitted to the surface atmosphere through the ventilation system. DOE estimated the amount of dust that would be emitted by the ventilation system by using engineering judgment and best available information (DIRS 104494-CRWMS M&O 1998, p. 37).

Table G-7 lists the release rates of PM_{10} for excavation activities. Table G-8 lists estimated air quality impacts from fugitive dust as pollutant concentration in air and percentage of regulatory limit.

Table G-7. Fugitive dust releases from excavation activities (PM_{10}).[a]

Period	Emission (kilograms)[b]	Emission rate (grams per second)[c]
Annual	920	0.029
24-hour	3.7	0.043[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on a 24-hour release period.

Table G-8. Fugitive dust (PM_{10}) and cristobalite air quality impacts (micrograms per cubic meter) from excavation activities.

Period	Maximum concentration[a]	Regulatory limit	Percent of regulatory limit[a]
PM_{10}			
Annual	0.0035	50	0.0070
24-hour	0.044	150	0.029
Cristobalite			
Annual	0.0010	10[b]	0.010

a. Numbers are rounded to two significant figures.
b. This value is a benchmark; there is no regulatory limit for cristobalite. See Section G.1.

Fugitive dust emissions from excavation operations would produce small offsite PM_{10} concentrations. Both annual and 24-hour average concentrations of PM_{10} would be much less than 1 percent of the regulatory standards. The highest estimated annual and 24-hour excavation rates, and hence the highest estimated fugitive dust concentrations, would be the same for all operating modes.

Dust generated during excavation would contain cristobalite, a naturally occurring form of crystalline silica discussed in Section G.1. The analysis estimated the amount of cristobalite released by multiplying the amount of dust released annually (shown in Table G-7) by the percentage of cristobalite in the parent rock (28 percent). Table G-8 also lists the potential air quality impacts for releases of cristobalite from excavation of the repository. Because there are no public exposure limits for cristobalite, the annual average concentration was compared to a derived benchmark level for the prevention of silicosis, as discussed in Section G.1. The offsite cristobalite concentration would be about 0.01 percent of this benchmark.

The air quality impacts from fugitive dust emissions from excavation operations during the construction phase would be the same for Modules 1 and 2 as for the Proposed Action.

G.1.4.3 Fugitive Dust from Excavated Rock Pile

The disposal and storage of excavated rock on the surface excavated rock pile would generate fugitive dust. Dust would be released during the unloading of the excavated rock and subsequent smoothing of the excavated rock pile, as well as by wind erosion of the material. DOE used the total suspended particulate emission for active storage piles to estimate fugitive dust emission (DIRS 103676-Cowherd, Muleski, and Kinsey 1988, pp. 4-17 to 4-37). The equation is:

$$E = 1.9 \times (s \div 1.5) \times [(365 - p) \div 235] \times (f \div 15)$$

where E = total suspended particulate emission factor (kilogram per day per hectare [1 hectare = 0.01 square kilometer = 2.5 acres])
s = silt content of aggregate (percent)
p = number of days per year with 0.25 millimeter or more of precipitation
f = percentage of time wind speed exceeds 5.4 meters per second (12 miles per hour) at pile height

For this analysis, *s* is equal to 4 percent, a conservative default value based on the average silt content of limestone quarrying material (DIRS 101824-EPA 1995, p. 13.2.4-2), *p* is 37.75 (DIRS 104497-Fosmire 1999, all) and *f* is 16.5 (calculated from meteorological data used in the Industrial Source Complex model). Thus, *E* is equal to 7.8 kilograms of total particulates per day per hectare (6.9 pounds per day per acre). Only about 50 percent of the total particulates would be PM_{10} (DIRS 103676-Cowherd, Muleski, and Kinsey 1988, pp. 4-17 to 4-37); therefore, the emission rate for PM_{10} would be 3.9 kilograms per day per hectare (3.5 pounds per day per acre).

The analysis estimated fugitive dust from disposal and storage using the size of the area actively involved in storage and maintenance. Only a portion of the excavated rock pile would be actively disturbed by the unloading of excavated rock and the subsequent contouring of the pile, and only that portion would be an active source of fugitive dust. The analysis assumed that the rest of the excavated rock pile would be stabilized by either natural processes or DOE stabilization measures and would release small amounts of dust. Dust suppression measures applied to the active area of the pile would reduce the calculated releases.

DOE based its estimate of the size of the active portion of the excavated rock pile on the amount of material it would store there each year (see Table G-9). The volume of rock placed on the excavated rock pile from excavation activities during the construction phase (DIRS 150941-CRWMS M&O 2000, p. 6-6; DIRS 155515-Williams 2001, Part 2, p. 12; Part 2, p. 10) was divided by the height of the storage pile. The average height of the excavated rock pile would be about 6 meters (20 feet) for the higher-temperature operating mode and about 8 meters high (26 feet) for the lower-temperature operating mode. The pile heights for Inventory Modules 1 and 2 would also be 6 meters for the higher-temperature operating mode and 8 to 9 meters for the lower-temperature operating mode. The active area of the excavated rock pile was estimated using the total area of the rock pile at the end of the construction phase divided by five years of construction, with this quantity then multiplied by two (DIRS 104505-Fosmire 1999, all).

Table G-9. Characteristics of excavated rock pile during the construction phase.[a,b]

Operating mode	Rock pile area (square kilometers)[c]	Pile height (meters)	Average annual active area (square kilometers)
Higher-temperature	0.27	6	0.11
Lower-temperature	0.26 - 0.28	8	0.10 - 0.11

a. Numbers are rounded to two significant figures.
b. The construction phase would last 5 years. Subsurface excavation and rock pile activities would continue during the operation and monitoring phase (see Section G.1.5).
c. To convert square kilometers to square miles, multiply by 0.3861.

Table G-10 lists the fugitive dust release rate from disposal and storage of the excavated rock pile for the operating modes. Table G-11 lists the air quality impacts from fugitive dust as pollutant concentration and percent of regulatory limit.

Fugitive dust emissions from the excavated rock pile during the construction phase would produce small offsite PM_{10} concentrations. Both the annual and 24-hour average concentrations of PM_{10} would be less than 1 percent of the regulatory standards.

Table G-10. Fugitive dust released from the excavated rock pile during the construction phase (PM_{10}).[a]

Operating mode	Period	Emission (kilograms)[b]	Emission rate (grams per second)[c]
Higher-temperature	Annual	16,000	0.49
	24-hour	42	0.49[d]
Lower-temperature	Annual	15,000 - 16,000	0.47 - 0.51
	24-hour	41 - 44	0.47 - 0.51[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on a continuous release.

Table G-11 also lists potential air quality impacts for releases of cristobalite. The methods used were the same as those described in Section G.1.4.2 for the construction phase, where cristobalite was assumed to be 28 percent of the fugitive dust released, based on its percentage in parent rock. The land withdrawal area boundary cristobalite concentration would be small, about 0.21 percent or less of the benchmark level discussed in Section G.1.

Table G-11. Fugitive dust (PM_{10}) and cristobalite air quality impacts (micrograms per cubic meter) from the excavated rock pile during the construction phase.

Operating mode	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
PM_{10}				
Higher-temperature	Annual	0.059	50	0.12
	24-hour	0.50	150	0.34
Lower-temperature	Annual	0.057 - 0.062	50	0.11 - 0.12
	24-hour	0.48 - 0.53	150	0.32 - 0.35
Cristobalite				
Higher-temperature	Annual	0.017	10[c]	0.17
Lower-temperature	Annual	0.016 - 0.017	10[c]	0.16 - 0.17

a. Numbers are rounded to two significant figures.
b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.
c. This value is a benchmark; there are no regulatory limits for cristobalite other than worker exposure limits. See Section G.1.

For Modules 1 and 2, the volume of rock excavated during the construction phase would be the same as that excavated for the Proposed Action (DIRS 152010-CRWMS M&O 2000, p. 6-6; DIRS 155515-Williams 2001, Part 1, p. 12; and Part 2, p. 10). The estimated air quality impacts would be identical for the Proposed Action and for Modules 1 and 2.

G.1.4.4 Fugitive Dust from Concrete Batch Facility

The concrete batch facility for the fabrication and curing of tunnel inverts and tunnel liners would emit dust. This facility would run 3 hours a day and would produce 100 cubic meters (130 cubic yards) of concrete per hour of operation (DIRS 104523-CRWMS M&O 1999, pp. 4-4 and 4-5). It would operate 250 days per year. Table G-12 lists emission factor estimates for the concrete batch facility (DIRS 101824-EPA 1995, pp. 11.12-1 to 11.12-5). About 0.76 cubic meter (1 cubic yard) of typical concrete weighs 1,800 kilograms (4,000 pounds) (DIRS 101824-EPA 1995, p. 11.12-3). The size of the aggregate storage pile for the concrete batch facility would be 800 square meters (0.2 acre) (DIRS 104523-CRWMS M&O 1999, pp. 4-4 and 4-5).

Table G-12. Dust release rates for the concrete batch facility (kilograms per 1,000 kilograms of concrete).[a,b]

Source/activity	Emission rate
Sand and aggregate transfer to elevated bin	0.014
Cement unloading to elevated storage silo	0.13
Weight hopper loading	0.01
Mixer loading	0.02
Wind erosion from aggregate storage	3.9 kilograms per hectare[c] per day

a. Source: DIRS 101824-EPA (1995, p. 11.12-3).
b. To convert kilograms to pounds, multiply by 2.2046.
c. 3.9 kilograms per hectare = about 21 pounds per acre.

Table G-13 lists the dust release rates of the concrete batch facility. Table G-14 lists estimated potential air quality impacts as the estimated pollutant concentration and percent of regulatory limit.

Table G-13. Dust release rates for the concrete batch facility during the construction phase (PM_{10}).[a]

Operating mode	Period	Emission (kilograms)[b]	Emission rate (grams per second)[c]
Higher-temperature	Annual	36,000	1.1
	24-hour	140	13[d]
Lower-temperature	Annual	36,000 - 46,000	1.1 - 1.5
	24-hour	140 - 180	13 - 17 [d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on a 3.5- to 4.5- hour release period.

Table G-14. Particulate matter (PM_{10}) air quality impacts (micrograms per cubic meter) from the concrete batch facility during the construction phase.

Operating mode	Period	Maximum concentration[a]	Regulatory limit	Percent of regulatory limit[a]
Higher-temperature	Annual	0.11	50	0.23
	24-hour	2.2	150	1.5
Lower-temperature	Annual	0.11 - 0.15	50	0.23 - 0.29
	24-hour	2.2 - 2.8	150	1.5 - 1.9

a. Numbers are rounded to two significant figures.

Dust emissions from the concrete batch facility during the operation and monitoring phase would produce small offsite PM_{10} concentrations. The annual and 24-hour averaged concentrations of PM_{10} would be less than 1 percent and about 2 percent of the regulatory standards, respectively.

For Modules 1 and 2, the air quality impacts from the concrete batch facility during the construction phase would be the same as for the Proposed Action.

G.1.4.5 Exhaust Emissions from Construction Equipment

Diesel- and gasoline-powered equipment would emit all four criteria pollutants during the construction phase. DIRS 103679-EPA (1991, pp. II-7-1 to II-7-7) provided pollutant emission rate estimates for heavy-duty equipment. This analysis assumed construction equipment would emit the average of the EPA reference emission rates. Emission rates from construction equipment could decrease significantly in the future. Legislation signed in early 2001 would create year 2007 emission standards that would reduce diesel vehicle emissions of particulate matter (90-percent reduction), nitrogen dioxide (95-percent reduction), and sulfur dioxide (97-percent reduction) (DIRS 155098-EPA 2000, all). Table G-15 lists the current emission rates for this equipment.

Table G-15. Pollutant emission rates (kilograms[a] per 1,000 liters[b] of fuel) for construction equipment.[c]

	Estimated emission	
Pollutant	Diesel	Gasoline
arbon monoxide	15	450
itrogen dioxide	39	13
M_{10}	3.5	0.86
ulfur dioxide	3.7	0.63

a. To convert kilograms to pounds, multiply by 2.2046.
b. To convert liters to gallons, multiply by 0.26418.
c. Source: Average of rates from DIRS 103679-EPA (1991, pp. II-7-1 to II-7-7).

Table G-16 lists the estimated average amount of fuel consumed per year during the construction phase. The fuel for the South Portal Development Area would include fuel consumed during maintenance of the excavated rock pile.

Table G-16. Amount of fuel consumed per year during the construction phase (liters).[a,b]

	South Portal Development Area		North Portal Operations Area[d]
Operating mode	Diesel	Gasoline	Diesel
Higher-temperature	300,000[c]	20,000[c]	770,000
Lower-temperature	430,000 - 460,000[e,f]	20,000[e]	770,000

a. To convert liters to gallons, multiply by 0.26418.
b. Numbers are rounded to two significant figures.
c. Source: Based on total fuel use from DIRS 150941-CRWMS M&O (2000, p. 6-3).
d. Source: Based on total fuel use from DIRS 152010-CRWMS M&O (2000, p. 48).
e. Source: Based on total fuel use from DIRS 155515-Williams (2001, Part 1, p. 9; and Part 2, p.7).
f. Source: Aging pad contribution derived from DIRS 152010-CRWMS M&O (2000, Table I-2).

Table G-17 lists pollutant releases from construction equipment for each operating mode. The emission rate for the annual concentration was calculated from the total fuel consumed, assuming the same amount of fuel would be consumed each year.

Table G-18 lists the impacts on air quality from construction equipment emission by operating mode as the maximum pollutant concentration in air and the percentage of the regulatory limit. Emissions from surface equipment during the construction phase would produce small offsite (outside the land withdrawal area) criteria pollutant concentrations. All concentrations would be less than 1 percent of the regulatory standards. The impacts from fuel use under Inventory Modules 1 and 2 would be the same as those under the Proposed Action because fuel use would be the same during construction.

G.1.4.6 Exhaust from Boiler

A proposed boiler in the North Portal Operations Area would emit the four criteria pollutants. The boiler would use diesel fuel and provide steam and hot water for the heating, ventilation, and air conditioning system. DOE assumed this boiler to be the same size as the boiler that would operate during the operation and monitoring phase (DIRS 152010-CRWMS M&O 2000, Table 6-2, p. 52). Table G-19 lists the annual emission rates of the boiler. To estimate the short-term (24 hours or less) emission rate, the analysis assumed the boiler would run 250 days (6,000 hours) per year. Given the annual boiler emissions, this was a conservative assumption because continuous operation 365 days (8,760 hours) per

Table G-17. Pollutant release rates from surface equipment during the construction phase.[a]

Pollutant	Period	Mass of pollutant per averaging period (kilograms)[b] South	Mass of pollutant per averaging period (kilograms)[b] North	Emission rate[c] (grams per second)[d] South	Emission rate[c] (grams per second)[d] North
Higher-temperature operating mode					
Nitrogen dioxide	Annual	12,000	30,000	0.38	0.95
Sulfur dioxide	Annual	1,100	2,900	0.036	0.090
	24-hour	4.5	12	0.16	0.40
	3-hour	1.7	4.3	0.16	0.40
Carbon monoxide	8-hour	54	47	1.9	1.6
	1-hour	6.7	5.8	1.9	1.6
PM_{10}	Annual	1,100	2,700	0.034	0.085
	24-hour	4.2	11	0.15	0.37
Lower-temperature operating mode					
Nitrogen dioxide	Annual	17,000 - 18,000	30,000	0.55 - 0.58	0.95
Sulfur dioxide	Annual	1,600 - 1,700	2,900	0.051 - 0.055	0.091
	24-hour	6.5 - 6.9	12	0.22 - 0.24	0.40
	3-hour	2.4 - 2.6	4.3	0.22 - 0.24	0.40
Carbon monoxide	8-hour	62 - 63	47	2.1 - 2.2	1.6
	1-hour	7.7 - 7.9	5.8	2.1 - 2.2	1.6
PM_{10}	Annual	1,500 - 1,600	2,700	0.048 - 0.051	0.085
	24-hour	6.1 - 6.5	11	0.040 - 0.043	0.37

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on an 8-hour release for averaging periods 24 hours or less.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-18. Air quality impacts from construction equipment during the construction phase (micrograms per cubic meter).[a]

Pollutant	Period	Maximum concentration	Regulatory limit[b]	Percent of regulatory limit
Higher-temperature operating mode				
Nitrogen dioxide	Annual	0.17	100	0.17
Sulfur dioxide	Annual	0.016	80	0.021
	24-hour	0.11	365	0.031
	3-hour	0.9	1,300	0.069
Carbon monoxide	8-hour	2.1	10,000	0.02
	1-hour	12	40,000	0.03
PM_{10}	Annual	0.015	50	0.03
	24-hour	0.1	150	0.07
Lower-temperature operating mode				
Nitrogen dioxide	Annual	0.18 - 0.19	100	0.18 - 0.19
Sulfur dioxide	Annual	0.017 - 0.018	80	0.022 - 0.023
	24-hour	0.12	365	0.033
	3-hour	0.95 - 0.98	1,300	0.073 - 0.075
Carbon monoxide	8-hour	2.1 - 2.2	10,000	0.021
	1-hour	12 - 13	40,000	0.031 - 0.032
PM_{10}	Annual	0.016	50	0.032 - 0.033
	24-hour	0.11	150	0.074 - 0.076

a. Numbers are rounded to two significant figures.
b. Source: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

Table G-19. Annual pollutant release rates (kilograms per year)[a] for the North Portal Operations Area boiler.[b,c]

Pollutant	Annual emission rate
Nitrogen dioxide	81,000
Sulfur dioxide	28,000
Carbon monoxide	20,000
PM_{10}	7,800

a. To convert kilograms to tons, multiply by 0.0011023.
b. Source: DIRS 152010-CRWMS M&O (2000, p. 52).
c. Numbers are rounded to two significant figures.

year would result in lower daily emissions. This assumption considered periods when the boiler would not be operating. The actual period of boiler operation is not known. In addition, specific information on the boiler stack height and exhaust air temperature (which would affect plume rise) has not been developed. These releases were assumed to be from ground level, which also tends to overestimate actual concentrations. Table G-20 lists releases of criteria pollutants by the boiler. Table G-21 lists estimated potential air quality impacts as pollutant concentrations in air and percent of regulatory limit.

Table G-20. Pollutant release rates from the boiler during the construction phase.[a,b]

Pollutant	Period	Mass of pollutant (kilograms)[c] per averaging time	Emission rate[d] (grams per second)[e]
Nitrogen dioxide	Annual	81,000	2.6
Sulfur dioxide	Annual	28,000	0.87
	24-hour	110	1.3
	3-hour	14	1.3
Carbon monoxide	8-hour	27	0.94
	1-hour	3.4	0.94
PM_{10}	Annual	7,800	0.25
	24-hour	32	0.36

a. Numbers are rounded to two significant figures.
b. These release rates also apply for the operation and monitoring phase (see Section G.1.5.6).
c. To convert kilograms to pounds, multiply by 2.2046.
d. Based on an 8-hour release for averaging periods of 24 hours or less.
e. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-21. Air quality impacts from boiler pollutant releases from the North Portal Operations Area during the construction phase (micrograms per cubic meter of pollutant).[a]

Pollutant	Period	Maximum concentration[b]	Regulatory limit[c]	Percent of regulatory limit[b]
Nitrogen dioxide	Annual	0.25	100	0.25
Sulfur dioxide	Annual	0.086	80	0.11
	24-hour	1.2	365	0.33
	3-hour	7.7	1,300	0.59
Carbon monoxide	8-hour	2.3	10,000	0.023
	1-hour	17	40,000	0.043
PM_{10}	Annual	0.025	50	0.050
	24-hour	0.34	150	0.23

a. These release rates also apply for the operation and monitoring phase (see Section G.1.5.6).
b. Numbers are rounded to two significant figures.
c. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

Emissions from the boiler during the construction phase would produce small offsite (outside the land withdrawal area) criteria pollutant concentrations. All concentrations would be less than 1 percent of the regulatory standards.

There would be no differences among repository operating modes. The air quality impacts from the boiler during the construction phase under Inventory Models 1 and 2 would be the same as those for the Proposed Action.

G.1.5 OPERATION AND MONITORING PHASE

This section describes the method DOE used to estimate air quality impacts during the operation and monitoring phase. As for the construction phase, impacts were evaluated for each year or for shorter time periods. Activities during this phase would include the continued development of the subsurface facilities, which would last 22 years for all operating modes. Emplacement activities in the surface and subsurface facilities would last 24 years, the first 22 years concurrent with continued development activities. Monitoring and maintenance would begin after the end of emplacement operations. For purposes of analysis, workers would use the following schedule for activities during the operation and monitoring phase: three 8-hour shifts a day, 5 days a week, 50 weeks a year. The maintenance of the excavated rock pile would occur in one 8-hour shift a day, 5 days a week, 50 weeks a year.

For Modules 1 and 2, the continued development of the subsurface facilities would last 36 years. Emplacement activities in the surface and subsurface facilities would continue concurrently with development operations but last an additional 2 years (38 years total).

The analysis estimated air quality impacts by calculating pollutant concentrations from various operation and monitoring activities. Emission rates were developed for each activity that would result in pollutant releases. The emission rates were multiplied by the unit release concentrations (see Section G.1.3) to calculate the pollutant concentration for comparison to the various regulatory limits.

The principal emission sources of particulates would be dust emissions from concrete batch facility operations and fugitive dust emissions from excavation and storage on the excavated rock pile. In addition, fugitive dust from earthmoving activities would be emitted during final aging pad construction. Fuel combustion from maintenance of the excavated rock pile and emissions from the North Portal boiler would be principal sources of nitrogen dioxide, sulfur dioxide, and carbon monoxide. The following sections describe these sources in more detail.

G.1.5.1 Fugitive Dust from Surface Construction

For the lower-temperature repository operating mode with aging, fugitive dust would be emitted when the remaining aging pads were constructed during the operation and monitoring phase. If the pads were constructed at a rate of 0.12 square kilometer (30 acres) per year, as in the construction phase (see Section G.1.4.1), the estimated maximum PM_{10} air concentrations would be 0.05 percent and 0.12 percent of the annual and daily regulatory limits, respectively, for PM_{10}.

G.1.5.2 Fugitive Dust from Concrete Batch Facility

The concrete batch facility for the fabrication and curing of tunnel inverts and liners, remaining surface facility construction (solar power and spent nuclear fuel aging facilities), and dry cask construction would emit dust. Batch plant daily run times would be shorter than those during the construction phase, ranging from 0.5 to 2.0 hours. The dust release rate and potential air quality impacts are listed in Tables G-22 and G-23, respectively.

Table G-22. Dust release rates for the concrete batch facility during the operation and monitoring phase (PM_{10})[a]

Operating Mode	Period	Emission (kilograms)[b]	Emission rate (grams per second)[c]
Higher-temperature	Annual	5,200	0.12
	24-hour	21	1.9[d]
Lower-temperature	Annual	10,000 - 21,000	0.33 - 0.65
	24-hour	41 - 83	3.8 - 7.6[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Higher-temperature based on 0.5-hour, lower-temperature on 1-to-2 hour release period.

Table G-23. Particulate matter (PM_{10}) air quality impacts (micrograms per cubic meter) from the concrete batch facility during the operation and monitoring phase.

Operating Mode	Period	Maximum concentration[a]	Regulatory limit	Percent of regulatory limit[a]
Higher-temperature	Annual	0.02	50	0.040
	24-hour	0.32	150	0.21
Lower-temperature	Annual	0.040 - 0.079	50	0.079 - 0.16
	24-hour	0.63 - 1.3	150	0.42 - 0.84

a. Numbers are rounded to two significant figures.

G.1.5.3 Fugitive Dust from Subsurface Excavation

The excavation of rock from the repository would generate fugitive dust in the drifts. Some of the dust would reach the external atmosphere through the repository ventilation system. Fugitive dust emission rates from excavation during operations would be the same as those during the construction phase. Thus, the fugitive dust release rate and potential air quality impacts for excavation of rock would be the same as those listed in Tables G-7 and G-8. Air quality impacts from cristobalite released during excavation of the repository would be the same as those listed in Table G-8.

G.1.5.4 Fugitive Dust from Excavated Rock Pile

The disposal and storage of excavated rock on the excavated rock pile would release fugitive dust. The analysis used the same method to estimate fugitive dust releases from the excavated rock pile during operations that it used for the construction phase (See Section G.1.4.3). Table G-24 lists the areas of the active portion of the excavated rock pile for each operating mode. The total land area used for storage and the active portion of the excavated rock pile was based on the amount of rock that would be stored during operations (DIRS 150941-CRWMS M&O 2000, p. 6-11; DIRS 155515-Williams 2001, Part 1, p. 17; and Part 2, p. 15). Sections G.1.4.1 and G.1.4.3 compare the excavated rock pile areas.

Table G-24. Characteristics of excavated rock pile area during subsurface excavation activities of the operation and monitoring phase.[a]

Operating mode	Rock pile area (square kilometers)[b]	Pile height (meters)	Annual average active area (square kilometers)
Higher-temperature	0.87	6	0.055
Lower-temperature	0.86 - 1.4	8	0.053 - 0.10

a. Numbers are rounded to two significant figures.
b. To convert square kilometers to acres, multiply by 247.1.

While the land area used for storage of excavated rock during the operation and monitoring phase would be nearly twice as large as that used during the construction phase for the higher-temperature repository operating mode, the active area per year would be about half of that for construction due to the larger number of years over which continued development would occur (22 years compared to 5 years). The land area used during the operation and monitoring phase would be 3 to 5 times that used during the construction phase. The stored volume of excavated rock would be larger during the operation and monitoring phase than during the construction phase. Table G-25 lists fugitive dust releases from the excavated rock pile; Table G-26 lists potential air quality impacts as the pollutant concentration and percent of the regulatory limit.

Table G-25. Fugitive dust release rate from the excavated rock pile during the operation and monitoring phase (PM_{10}).[a]

Operating mode	Period	Emissions (kilograms)[b]	Emission rate[c] (grams per second)[d]
Higher-temperature	Annual	7,800	0.25
	24-hour	21	0.25
Lower-temperature	Annual	7,600 - 15,000	0.24 - 0.46
	24-hour	21 - 40	0.24 - 0.46

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on a continuous release.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-26. Fugitive dust (PM_{10}) and cristobalite air quality impacts from the excavated rock pile during the operation and monitoring phase (micrograms per cubic meter).

Operating mode	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
PM_{10}				
Higher-temperature	Annual	0.03	50	0.06
	24-hour	0.25	150	0.17
Lower-temperature	Annual	0.029 - 0.056	50	0.058 - 0.11
	24-hour	0.25 - 0.47	150	0.16 - 0.32
Cristobalite				
Higher-temperature	Annual	0.0084	10[c]	0.084
Lower-temperature	Annual	0.0081 - 0.016	10[c]	0.081 - 0.16

a. Numbers are rounded to two significant figures.
b. Source: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.
c. This value is a benchmark; there is no regulatory limit for cristobalite. See Section G.1.

Fugitive dust emissions from the excavated rock pile during the operation and monitoring phase would produce very small offsite (outside the land withdrawal area) PM_{10} concentrations. Both annual and 24-hour average concentrations of PM_{10} would be less than 1 percent of the regulatory standards for all operating modes.

Table G-26 also lists potential air quality impacts for releases of cristobalite. The methods used were the same as those described in Section G.1.4.2 for the construction phase, where cristobalite was assumed to be 28 percent of the fugitive dust released, based on its percentage in parent rock. The site boundary cristobalite concentration would be small, about 0.1 percent of the benchmark level discussed in Section G.1.

The Module 1 and 2 analysis used the same technique as for the Proposed Action. The stored rock pile area for Inventory Modules 1 and 2 would be approximately twice the size of the piles for the Proposed

Action operating modes, but the excavation period would be extended as well. The estimated air quality impacts would be only 1.2 times larger for Modules 1 and 2.

G.1.5.5 Exhaust from Surface Equipment

Surface equipment would emit the four criteria pollutants during excavated rock pile maintenance, surface operation, and any remaining surface facility construction. The analysis used the same method to determine air quality impacts for surface equipment during operations used for the construction phase (see Section G.1.4.5). Table G-15 lists the pollutant release rates of the equipment. Table G-27 lists the average amount of fuel consumed each year during the operation and monitoring phase at the South Portal Development Area.

Table G-27. Annual amount of fuel (liters)[a] consumed during the operation and monitoring phase.[b]

Operating mode	Diesel	Gasoline
Higher-temperature[c]	170,000	4,500
Lower-temperature[d]	210,000 - 400,000[e]	4,500

a. To convert liters to gallons, multiply by 0.26418.
b. Numbers are rounded to two significant figures.
c. Source: Based on total fuel use from DIRS 150941-CRWMS M&O (2000, pp. 6-8 and 6-13).
d. Source: DIRS 155515-Williams (2001, Part 1, pp. 14 and 18; Part 2, pp. 12 and 16).
e. Source: Derived using DIRS 152010-CRWMS M&O (2000, Table I-2).

Table G-28 lists pollutant release rates for surface equipment during operations activities of the operation and monitoring phase. Monitoring activity emissions would be much smaller. Table G-29 lists potential air quality impacts.

Table G-28. Pollutant release rates from surface equipment during the operation and monitoring phase.[a]

Pollutant	Period	Mass of pollutant per averaging time (kilograms)[b]	Emission rate[c] (grams per second)[d]
Higher-temperature operating mode			
Nitrogen dioxide	Annual	13,000	0.41
Sulfur dioxide	Annual	1,200	0.039
	24-hour	4.9	0.17
	3-hour	1.8	0.17
Carbon monoxide	8-hour	28	0.97
	1-hour	3.5	0.97
PM_{10}	Annual	1,100	0.036
	24-hour	4.6	0.16
Lower-temperature operating mode			
Nitrogen dioxide	Annual	14,000 - 20,000	0.46 - 0.62
Sulfur dioxide	Annual	1,400 - 1,900	0.044 - 0.059
	24-hour	5.5 - 7.5	0.19 - 0.26
	3-hour	2.1 - 2.8	0.19 - 0.26
Carbon monoxide	8-hour	30 - 38	1 - 1.3
	1-hour	3.8 - 4.8	1 - 1.3
PM_{10}	Annual	1,300 - 1,700	0.041 - 0.055
	24-hour	5.1 - 7	0.18 - 0.24

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on an 8-hour release for averaging periods of 24 hours or less.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-29. Air quality impacts from surface equipment during the operation and monitoring phase (micrograms per cubic meter of pollutant).

Pollutant	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
Higher-temperature operating mode				
Nitrogen dioxide	Annual	0.052	100	0.052
Sulfur dioxide	Annual	0.0049	80	0.0062
	24-hour	0.034	365	0.0093
	3-hour	0.27	1,300	0.021
Carbon monoxide	8-hour	0.57	10,000	0.0056
	1-hour	3.3	40,000	0.0083
PM_{10}	Annual	0.0046	50	0.0091
	24-hour	0.032	150	0.021
Lower-temperature operating mode				
Nitrogen dioxide	Annual	0.058 - 0.078	100	0.058 - 0.078
Sulfur dioxide	Annual	0.0055 - 0.0073	80	0.0070 - 0.0094
	24-hour	0.038 - 0.051	365	0.01 - 0.014
	3-hour	0.3 - 0.41	1,300	0.023 - 0.031
Carbon monoxide	8-hour	0.62 - 0.78	10,000	0.006 - 0.0076
	1-hour	3.6 - 4.5	40,000	0.009 - 0.011
PM_{10}	Annual	0.0051 - 0.0069	50	0.01 - 0.014
	24-hour	0.035 - 0.047	150	0.024 - 0.032

a. Numbers are rounded to two significant figures.
b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

Emissions from surface equipment during operation and monitoring would produce very small concentrations of offsite (outside the land withdrawal area) criteria pollutants. All estimated concentrations would be less than 1 percent of the regulatory standards.

Modules 1 and 2 would use fuel at a slightly higher rate than that for the Proposed Action at the South Portal Development Area, but at a slightly lower rate at the North Portal Operations Area. The resulting impact under Modules 1 and 2 would be the same; all estimated concentrations would be less than 1 percent of the regulatory standard.

G.1.5.6 Exhaust from Boiler

A boiler in the North Portal Operations Area would emit the four criteria pollutants. The annual emission rates are listed in Table G-19. There would be small variations in the boiler emissions for the transportation and waste packaging options because of different operational requirements. The emissions listed in Table G-19 are for the combination of legal-weight truck transport and uncanistered waste scenario, which would require the largest boiler because a larger Waste Handling Building would be required (DIRS 152010-CRWMS M&O 2000, p. 52). (The analysis assumed that identical boilers would operate under all operating modes and that the boiler would run 250 days (6,000 hours) per year.) Given an annual emission rate, this was a conservative assumption because continuous operation 365 days (8,760 hours) per year would result in lower daily emissions. This assumption considered periods when the boiler would not be operating. The actual period of boiler operation is not known. Pollutant release rates during the operation and monitoring phase would be the same as those listed in Table G-20. Table G-21 lists estimated potential air quality impacts as pollutant concentrations in air and percent of regulatory limit. Emissions from the boiler during the operation and monitoring phase would produce small offsite criteria pollutant concentrations. All concentrations would be less than 1 percent of the regulatory standards.

The estimated air quality impacts from boilers for Inventory Modules 1 and 2 during the operation and monitoring phase would be the same as those for the Proposed Action.

G.1.6 CLOSURE PHASE

This section describes the method used to estimate air quality impacts during the closure phase at the proposed repository. The closure phase is defined by the length of the subsurface closure activities, which would be directed from the South Portal Development Area. Subsurface closure for the higher-temperature operating mode of the Proposed Action would last 10 years, while subsurface closure for the lower-temperature operating mode would range from 11 to 17 years. Surface facility closure at the North Portal Operations Area would last 6 years for all operating modes. Closure of any aging pads that might be present under the lower-temperature operating mode was assumed to take place after surface facility closure was completed. Closure for Inventory Modules 1 and 2 would have a longer subsurface closure period, lasting 12 years for the higher-temperature operating mode and from 16 to 23 years for the lower-temperature operating mode. Surface facility closure for Inventory Modules 1 and 2 would be the same as for the Proposed Action. The work schedule would be one 8-hour shift per day, 5 days a week, 50 weeks a year.

Air quality impacts were estimated by calculating pollutant concentrations from various closure activities. Emission rates were developed for each activity that would result in releases of pollutants. These pollutant emission rates were then multiplied by the unit release concentration (see Section G.1.3) to calculate the pollutant concentration for comparison to the various regulatory limits.

The sources of particulates would be emissions from the backfill plant and the concrete batch facility and fugitive dust from closure activities on the surface and the reclamation of material from the excavated rock pile for backfill. The principal source of nitrogen dioxide, sulfur dioxide, and carbon monoxide during closure would be fuel combustion. The following sections describe these sources in more detail.

G.1.6.1 Dust from Backfill Plant

The Closure Backfill Preparation Plant would process (separate, crush, screen, and wash) rock from the excavated rock pile for use as backfill for the underground access openings (DIRS 104523-CRWMS M&O 1999, pp. 4-77 and 4-78). The facility would have the capacity to handle 91 metric tons (100 tons) an hour (DIRS 104523-CRWMS M&O 1999, pp. 4-77 and 4-78). For purposes of analysis, the backfill plant would run 6 hours a shift, 2 shifts a day, 5 days a week, 50 weeks a year during the closure phase.

The plant was assumed to have emissions similar to a crushed-stone processing plant. Table G-30 lists the emission rates for various activities associated with a crushed stone processing plant (DIRS 101824-EPA 1995, pp. 11.19.2-1 to 11.19.2-8). Table G-31 lists estimated pollutant release rates for the backfill plant. Table G-32 lists potential air quality impacts as pollutant concentrations in air and percent of regulatory limit.

Table G-30. Emission rates from a crushed stone processing plant.[a,b]

Source/activity	Emission rate (kilogram[c] per 1,000 kilograms of material processed)
Dump to conveyor or truck	0.00005
Screening	0.0076
Crusher	0.0012
Fine screening	0.036

a. Source: DIRS 101824-EPA (1995, pp. 11.19.2-1 to 11.19.2-8).
b. Numbers are rounded to two significant figures.
c. To convert kilograms to pounds, multiply by 2.2046.

Table G-31. Dust release rates from the backfill plant (PM_{10}).[a]

Period	Emission (kilograms)[b]	Emission rate (grams per second)[c]
Annual	12,000 per year	0.39
24-hour	49 per day	1.1[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on a 12-hour release period.

Table G-32. Particulate matter (PM_{10}) air quality impacts from backfill plant (micrograms per cubic meter).

Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
Annual	0.047	50	0.093
24-hour	1.1	150	0.71

a. Numbers are rounded to two significant figures.
b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

Dust emissions from the backfill plant would produce small PM_{10} concentrations. Both annual and 24-hour average concentrations of PM_{10} would be less than 1 percent of the regulatory standards for all operating modes.

For Modules 1 and 2, the estimated air quality impacts for the backfill plant would be the same as those for the Proposed Action.

G.1.6.2 Fugitive Dust from Concrete Batch Facility

A concrete batch facility for the fabrication of seals would be similar to the facility that would operate during the construction and operation and monitoring phases (see Sections G.1.4.4 and G.1.5.2). The only difference would be that it would run only ten 3-hour shifts a year per concrete seal (DIRS 104523-CRWMS M&O 1999, p. 4-78). The analysis assumed that two seals per year would be produced. Table G-12 lists activities associated with the concrete batch facility and their emissions. Table G-33 lists emissions from the concrete batch facility during closure. Table G-34 lists potential air quality impacts as pollutant concentration in air and percent of regulatory limit.

Table G-33. Dust release rates from the concrete batch facility during the closure phase (PM_{10}).[a]

Period	Mass of pollutant (kilograms)[b]	Emission rate (grams per second)[c]
Annual	1,300	0.043
24-hour	120	11[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on a 3-hour release period.

Dust emissions from the concrete batch facility during closure would produce small offsite (outside the land withdrawal area) PM_{10} concentrations. The annual and 24-hour average concentrations of PM_{10} would be less than 1 percent and around 1.3 percent, respectively, of the regulatory standards.

For Modules 1 and 2, the estimated air quality impacts from the concrete batch facility during the closure phase would be the same as those for the Proposed Action.

Table G-34. Particulate matter (PM_{10}) air quality impacts from the concrete batch facility during the closure phase (micrograms per cubic meter).

Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
Annual	0.0051	50	0.01
24-hour	1.9	150	1.3

a. Numbers are rounded to two significant figures.
b. Source: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

G.1.6.3 Fugitive Dust from Closure Activities

Closure activities such as smoothing and reshaping the excavated rock pile and demolishing buildings would produce virtually the same fugitive dust releases as construction activities because they would disturb nearly the same amount of land. Sources of dust from surface demolition and decommissioning activities would include the North Portal area and roads, South portal area and roads, ventilation shaft areas and access roads, the excavated rock pile, solar power generating facility, concrete batch plant and, for some aspects of the lower-temperature operating mode, concrete spent nuclear fuel aging pads. Because some of these surface facilities would be needed to support subsurface closure activities, releases from surface demolition and decommissioning would last for the duration of the closure phase, not just the 6 years of closure at the North Portal Operations Area. Potential dust releases and impacts from the lower-temperature operating mode would be somewhat lower than from the higher-temperature operating mode because a similar scope of activities would occur over the longer closure phase. Dust release rates and potential air quality impacts are listed in Tables G-35 and G-36, respectively.

Table G-35. Fugitive dust releases from surface demolition and decommissioning (PM_{10}).[a]

Operating mode	Period	Pollutant emission (kilograms)[b]	Emission rate (grams per second)[c]
Higher-temperature	Annual	62,000 per year	2
	24-hour	250 per day	8.6[d]
Lower-temperature	Annual	52,000 - 60,000 per year	1.6 - 1.9
	24-hour	210 - 240 per day	7.3 - 8.3[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on an 8-hour release period.

Table G-36. Estimated fugitive dust air quality impacts (micrograms per cubic meter) from surface demolition and decommissioning (PM_{10}).[a]

Operating mode	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of limit[a]
Higher-temperature	Annual	0.24	50	0.47
	24-hour	1.6	150	1.1
Lower-temperature	Annual	0.2 - 0.23	50	0.4 - 0.46
	24-hour	1.4 - 1.6	150	0.92 - 1.1

a. Numbers are rounded to two significant figures.
b. Source: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

Fugitive dust emissions would produce small offsite PM_{10} concentrations. The annual and 24-hour average concentrations of PM_{10} would be less than 0.5 percent and around 1.1 percent, respectively, of the regulatory standards. The estimated air quality impacts from surface facility closure for Inventory Modules 1 and 2 would be the same as those for the Proposed Action.

G.1.6.4 Fugitive Dust from Excavated Rock Pile

During backfill operations, fugitive dust would occur from the removal of excavated rock from the storage pile. The analysis used the same method to estimate fugitive dust emission from the excavated rock pile during the closure phase that it used for the construction phase (Section G.1.4.3). Table G-37 lists the total area of the excavated rock pile disturbed and the active portion, based on the amount of material to be removed from the pile (DIRS 104523-CRWMS M&O 1999, p. 6-39; DIRS 150941-CRWMS M&O 2000, p. 6-24). The analysis assumed that the rock used in backfill would be from a limited area of the excavated rock pile, rather than from all over the pile. Table G-38 lists fugitive dust releases from the excavated rock pile. Table G-39 lists potential air quality impacts from the pile as pollutant air concentration and percent of regulatory limit.

Table G-37. Characteristics of excavated rock pile during the closure phase.[a]

Operating mode	Rock pile area (square kilometers)[b]	Pile height (meters)[c]	Annual average active area (square kilometers)
Higher-temperature	0.39	6	0.077
Lower-temperature	0.54 - 0.83	8	0.059 - 0.065

a. Numbers are rounded to two significant figures.
b. To convert square kilometers to acres, multiply by 247.1.
c. To convert meters to feet, multiply by 3.2808.

Table G-38. Fugitive dust release rates from the excavated rock pile during the closure phase (PM_{10}).[a]

Operating mode	Period	Emission (kilograms)[b]	Emission rate[c] (grams per second)[d]
Higher-temperature	Annual	11,000	0.35
	24-hour	30	0.35
Lower-temperature	Annual	8,300 - 9,200	0.26 - 0.29
	24-hour	23 - 25	0.26 - 0.29

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on a continuous release.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-39. Fugitive dust (PM_{10}) and cristobalite air quality impacts from the excavated rock pile during the closure phase (micrograms per cubic meter).

Operating mode	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
PM_{10}				
Higher-temperature	Annual	0.042	50	0.084
	24-hour	0.36	150	0.24
Lower-temperature	Annual	0.032 - 0.035	50	0.064 - 0.070
	24-hour	0.27 - 0.30	150	0.18 - 0.20
Cristobalite				
Higher-temperature	Annual	0.012	10[c]	0.12
Lower-temperature	Annual	0.0089 - 0.0098	10[c]	0.089 - 0.098

a. Numbers are rounded to two significant figures.
b. Source: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.
c. This value is a benchmark; there is no regulatory limit for cristobalite. See Section G.1.

Fugitive dust emissions from the excavated rock pile during closure would produce small offsite PM_{10} concentrations. Both the annual and 24-hour average concentrations of PM_{10} would be less than 1 percent of the regulatory standards for all operating modes.

Table G-39 also lists potential air quality impacts for releases of cristobalite. The methods used were the same as those described in Section G.1.4.2 for the construction phase, where cristobalite was assumed to be 28 percent of the fugitive dust released, based on its percentage in parent rock. The land withdrawal area boundary cristobalite concentration would be small, about 0.1 percent of the benchmark level discussed in Section G.1.

For Modules 1 and 2, the same technique was used. The estimated active area of the rock pile would be 13 percent larger for the higher-temperature repository operating mode and 12 to 30 percent larger for the lower-temperature repository operating mode. The estimated air quality impacts would be just slightly larger than those of the Proposed Action because of longer closure times under Modules 1 and 2. Impacts would be less than 1 percent of the regulatory standards.

G.1.6.5 Exhaust Emissions from Surface Equipment

The consumption of diesel fuel by surface equipment and backfilling equipment would emit the four criteria pollutants during closure. The analysis used the same method to determine pollutant release rates during closure as was used for the construction phase (see Section G.1.4.5). Table G-15 lists the estimated pollutant release rates of the equipment that would consume the fuel. Table G-40 lists the average amount of fuel consumed per year. The length of the closure phase is discussed in Section G.1.6. The analysis assumed backfilling operations would last 2 years (DIRS 150941-CRWMS M&O 2000, p. I-2).

Table G-40. Annual amount of fuel consumed (liters)[a] during the closure phase.[b]

Operating mode	South Portal diesel	North Portal diesel[d]	Backfilling diesel[e,f]	Maximum annual usage
Higher-temperature	150,000[c]	620,000	1,250,000	2,000,000
Lower-temperature	150,000-170,000[g]	620,000	1,250,000	2,000,000

a. To convert liters to gallons, multiply by 0.26418.
b. Numbers are rounded to two significant figures.
c. Source: Based on total fuel consumed from DIRS 150941-CRWMS M&O (2000, p. 6-23).
d. Source: Based on total fuel consumed from DIRS 152010-CRWMS M&O (2000, p. 57).
e. Source: Based on total fuel consumed from DIRS 150941-CRWMS M&O (2000, p. I-2).
f. Backfilling operations would last only 2 years.
g. Source: Based on total fuel consumed from DIRS 155515-Williams (2001, Part 1, p. 25; and Part 2, p. 22).

Tables G-41 and G-42 list pollutant releases from surface diesel consumption. Table G-43 lists potential air quality impacts as pollutant concentrations in air and percent of regulatory limit. Concentrations would be less than 1 percent of the regulatory limit for the range of operating modes.

G.1.7 RETRIEVAL SCENARIO

This section describes the method used to estimate air quality impacts during possible retrieval at the proposed repository. Retrieval is not part of the Proposed Action; DOE evaluated it only as a contingent action of the higher-temperature operating mode. The retrieval contingency would last 14 years and include additional construction activities and retrieval operations. Construction of the retrieval storage facility and pads would take 10 years (DIRS 152010-CRWMS M&O 2000, p. I-17). There would be an initial 3-year period of construction (DIRS 152010-CRMWS M&O 2000, p. I-16), followed by 7 years of construction that would take place concurrently with retrieval operations. Retrieval operations would last

Table G-41. Pollutant release rates from surface equipment during the closure phase.[a]

Pollutant	Period	Mass of pollutant per averaging period (kilograms)[b] South	Mass of pollutant per averaging period (kilograms)[b] North	Emission rate[c] (grams per second)[d] South	Emission rate[c] (grams per second)[d] North
Higher-temperature operating mode					
Nitrogen dioxide	Annual	5,900	24,000	0.19	0.76
Sulfur dioxide	Annual	560	2,300	0.018	0.073
	24-hour	2.2	9.2	0.078	0.32
	3-hour	0.84	3.4	0.078	0.32
Carbon monoxide	8-hour	9.1	37	0.31	1.3
	1-hour	1.1	4.6	0.31	1.3
PM_{10}	Annual	520	2,100	0.017	0.068
	24-hour	2.1	8.6	0.073	0.3
Lower-temperature operating mode					
Nitrogen dioxide	Annual	5,900 - 6,600	24,000	0.19 - 0.21	0.76
Sulfur dioxide	Annual	560 - 625	2,300	0.018 - 0.02	0.073
	24 - hour	2.2 - 2.5	9.2	0.078 - 0.087	0.32
	3 - hour	0.84 - 0.94	3.4	0.078 - 0.087	0.32
Carbon monoxide	8 - hour	9.1 - 10	37	0.31 - 0.35	1.3
	1 - hour	1.1 - 1.3	4.6	0.31 - 0.35	1.3
PM_{10}	Annual	520 - 580	2,100	0.017 - 0.018	0.068
	24 - hour	2.1 - 2.3	8.6	0.073 - 0.081	0.3

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on an 8-hour release period for averaging periods of 24 hours or less.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-42. Pollutant release rates from diesel backfilling equipment during the closure phase for the higher- and lower-temperature repository operating modes.[a]

Pollutant	Period	Mass of pollutant per averaging time (kilograms)[b]	Emission rate[c] (grams per second)[d]
Nitrogen dioxide	Annual	49,000	1.6
Sulfur dioxide	Annual	4,700	0.15
	24-hour	19	0.65
	3-hour	7.0	0.65
Carbon monoxide	8-hour	75	2.6
	1-hour	9.4	2.6
PM_{10}	Annual	4,400	0.14
	24-hour	17	0.60

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on an 8-hour release for averaging periods of 24 hours or less.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

11 years (DIRS 152010-CRMWS M&O 2000, p. I-17), continuing 4 years after the construction was completed. If the lower-temperature operating mode with aging was implemented, the aging pads constructed could be used for storage of retrieved waste packages. The analysis considered concurrent air quality impacts of retrieval and construction. The retrieval scenario work schedule would be one 8-hour shift a day, 5 days a week, 50 weeks a year.

The analysis estimated air quality impacts by calculating pollutant concentrations from various activities associated with retrieval. Emission rates were developed for each activity that would result in releases of pollutants. These rates were multiplied by the unit release concentration (see Section G.1.3) to calculate pollutant concentrations for comparison to the various regulatory limits. The principal sources of particulates would be fugitive dust emissions from construction activities associated with the waste retrieval facility, and a concrete batch facility. The principal source of nitrogen dioxide, sulfur dioxide, and carbon monoxide would be fuel combustion during the construction of the waste retrieval facility and during retrieval of the waste. The following sections describe these sources in more detail.

Table G-43. Air quality impacts (micrograms per cubic meter) from surface equipment during the closure phase.

Pollutant	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
Higher-temperature operating mode				
Nitrogen dioxide	Annual	0.3	100	0.3
Sulfur dioxide	Annual	0.029	80	0.037
	24-hour	0.2	365	0.055
	3-hour	1.6	1,300	0.12
Carbon monoxide	8-hour	2.4	10,000	0.024
	1-hour	14	40,000	0.035
PM_{10}	Annual	0.027	50	0.054
	24-hour	0.19	150	0.12
Lower-temperature operating mode				
Nitrogen dioxide	Annual	0.3 - 0.31	100	0.31
Sulfur dioxide	Annual	0.029	80	0.037
	24-hour	0.20	365	0.055
	3-hour	1.6	1,300	0.12
Carbon monoxide	8-hour	2.4	10,000	0.024
	1-hour	14	40,000	0.035
PM_{10}	Annual	0.027	50	0.054
	24-hour	0.19	150	0.12

a. Numbers are rounded to two significant figures.
b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

G.1.7.1 Fugitive Dust from Construction of Retrieval Storage Facility

Construction activities such as earth moving and truck traffic would produce fugitive dust during the construction of the retrieval storage facility. The analysis used the same method to estimate fugitive dust releases during retrieval as that for construction (see Section G.1.4.1). The amount of land disturbed to build the retrieval storage facility and storage pads would be 1.5 square kilometer (380 acres) (DIRS 152010-CRWMS M&O 2000, Table I-2, p. I-22).

Table G-44 lists fugitive dust release rates from construction of the retrieval facility and storage pad. Table G-45 lists air quality impacts as pollutant concentration in air and percent of regulatory limit. Fugitive dust emissions from construction of the retrieval facility and storage pad would produce small offsite (outside the land withdrawal area) PM_{10} concentrations. Annual and 24-hour average concentrations of PM_{10} would be less than 1 percent of the regulatory standards for all operating modes.

Table G-44. Fugitive dust release rates from surface construction of retrieval storage facility and storage pad (PM_{10}).[a]

Period	Pollutant emission (kilograms)[b]	Emission rate (grams per second)[c]
Annual	34,000 per year	1.1
24-hour	140 per day	4.8[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on an 8-hour release period.

Table G-45. Fugitive dust (PM_{10}) air quality impacts from surface construction of the retrieval storage facility and storage pad (micrograms per cubic meter).

Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
Annual	0.11	50	0.22
24-hour	0.87	150	0.58

a. Numbers are rounded to two significant figures.
b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

G.1.7.2 Concrete Batch Plant

The concrete batch plant used during the retrieval phase was assumed to operate 3 hours per day, 250 days per year. The emissions would be approximately 85 percent of those indicated for the higher-temperature repository operating mode concrete batch plant during the construction phase (see Tables G-13 and G-14). The numbers would be lower because of the lower daily operating time (3 hours per day rather than 3.5 hours per day). The annual and 24-hour averaged concentrations of PM_{10} from the concrete batch plant would be less than 1 percent and 2 percent of the regulatory standards, respectively.

G.1.7.3 Exhaust from Surface Equipment

Surface equipment would emit the four criteria pollutants during retrieval operations and during the construction of the retrieval storage facility and storage pad. The analysis used the same method to estimate pollutant release rates from fuel consumed by construction equipment during retrieval that was used for the construction phase (see Section G.1.4.5). During retrieval operations, fuel would be consumed at the South Portal Development Area; during the construction of the retrieval facility and storage pad, fuel would be consumed at the North Portal Operations Area. Table G-15 lists the pollutant release rates of the equipment that would consume the diesel fuel. The fuel would be used for surface construction and surface and subsurface retrieval operations. Total annual usage for the Proposed Action would be 250,000 liters (66,000 gallons) of diesel fuel at the South Portal; 190,000 liters (50,000 gallons) at the North Portal; and 18,000 liters (4,800 gallons) for retrieval operations at the North Portal.

Table G-46 lists pollutant release rates for surface equipment during retrieval. Table G-47 lists the potential air quality impacts. Emissions from surface equipment during retrieval would produce small offsite criteria pollutant concentrations. All concentrations would be less than 1 percent of the regulatory standards.

Table G-46. Pollutant release rates from surface equipment during the retrieval scenario.[a]

Pollutant	Period	Mass of pollutant per averaging time (kilograms)[b]	Emission rate[c] (grams per second)[d]
Nitrogen dioxide	Annual	9,100	0.29
Sulfur dioxide	Annual	860	0.027
	24-hour	3.4	0.12
	3-hour	1.3	0.12
Carbon monoxide	8-hour	14	0.48
	1-hour	1.7	0.48
PM_{10}	Annual	800	0.025
	24-hour	3.2	0.11

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on an 8-hour release period for averaging periods of 24 hour or less.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-47. Air quality impacts from surface equipment during the retrieval scenario (micrograms per cubic meter of pollutant).

Pollutant	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
Nitrogen dioxide	Annual	0.035	100	0.035
Sulfur dioxide	Annual	0.003	80	0.0042
	24-hour	0.023	365	0.0062
	3-hour	0.18	1,300	0.014
Carbon monoxide	8-hour	0.28	10,000	0.0027
	1-hour	1.6	40,000	0.004
PM_{10}	Annual	0.0031	50	0.0061
	24-hour	0.021	150	0.014

a. Numbers are rounded to two significant figures.
b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

G.2 Radiological Air Quality

This section describes the methods DOE used to analyze potential radiological impacts to air quality at the proposed Yucca Mountain Repository during the construction, operation and monitoring, and closure phases, and a possible retrieval scenario. The results are presented in Chapter 4, Section 4.1.2. It discusses the radioactive noble gas krypton-85, which would be released from surface facilities during the handling of spent nuclear fuel, and naturally occurring radon-222 and its radioactive decay products, which would be released from the rock to the subsurface facility and then to the ventilation air. The excavated rock pile would not be a notable additional source of radon-222, because the rock would not have enhanced concentrations of uranium or radium (the sources of radon-222) in comparison to surface rock. Somewhat higher concentrations of radon-222 could be present at the rock pile itself but, in general, concentrations of radon-222 released from the excavated rock pile would not differ greatly from naturally occurring surface concentrations of radon.

G.2.1 LOCATIONS OF HYPOTHETICALLY EXPOSED INDIVIDUALS AND LOCATIONS

Members of the public and noninvolved workers could be exposed to atmospheric releases of radionuclides from repository activities. Doses to the maximally exposed individual and population within 80 kilometers (50 miles) were evaluated for the public. The dose to the maximally exposed noninvolved worker and the noninvolved worker populations at the repository and at the Nevada Test Site were also evaluated.

Public

The location of the maximally exposed individual member of the public would be at the southern boundary of the land withdrawal area. This was determined to be the location of unrestricted public access that would have the highest annual average concentration of airborne radionuclides (see Section G.2.2). Twenty kilometers (12 miles) was used as a representative distance to the exposed individual location for releases to air from the North Portal, South Portal, and one to nine exhaust ventilation shafts over three project phases and the range of operating modes. The locations calculated for nonradiological air quality impacts (Section G.1.2) are somewhat different because the analysis estimated exposure to nonradiological pollutants for acute (short-term) exposures (1 to 24 hours) and for annual (continuous) exposures.

Table G-48 lists the estimated population of about 76,000 within 80 kilometers (50 miles) of the repository. This is the predicted population for 2035, based on projected changes in the region, including the towns of Beatty, Pahrump, Indian Springs, and the surrounding rural areas. These projections are based on information from State and local sources (see Chapter 3, Section 3.1.7) The population in the vicinity of Pahrump was included in Table G-48 and evaluated for air quality impacts, even though the population extends beyond the 80-kilometer region. The analysis calculated both annual population dose and cumulative dose for the project phases of 115 to 341 years of construction, operation and monitoring, and closure.

Table G-48. Projected 2035 population distribution within 80 kilometers (50 miles) of repository site.[a,b,c]

	Distance (kilometers)										
Direction	8	16	24	32	40	48	56	64	72	80	***Totals***
S	0	0	49	660	1,376	363	0	19	0	0	***2,467***
SSW	0	0	0	928	179	0	0	4	0	0	***1,111***
SW	0	0	0	0	0	0	596	62	0	0	***658***
WSW	0	0	0	0	0	0	0	0	107	0	***107***
W	0	0	0	1,092	10	0	0	0	0	0	***1,102***
WNW	0	0	63	1,829	0	0	0	0	0	11	***1,903***
NW	0	0	0	50	2	0	0	5	50	0	***105***
NNW	0	0	0	0	0	0	0	0	0	0	***0***
N	0	0	0	0	0	0	0	0	0	0	***0***
NNE	0	0	0	0	0	0	0	0	0	0	***0***
NE	0	0	0	0	0	0	0	0	0	0	***0***
ENE	0	0	0	0	0	0	0	0	0	0	***0***
E	0	0	0	0	0	0	0	0	0	0	***0***
ESE	0	0	0	0	0	0	0	0	2,686	0	***2,686***
SE	0	0	0	0	0	0	50	0	0	1,086	***1,136***
SSE	0	0	0	0	41	187	49	177	18,249	46,080[d]	***64,783***
Grand Total											***76,058***

a. Source: DIRS 155105-Baxter (2001, all).
b. To convert kilometers to miles, multiply by 0.62137.
c. There is a 4-kilometer (about 2.5-mile)-radius area around the North Portal, from which the analysis determined the 80-kilometer (50-mile) area.
d. Includes the Pahrump vicinity population, which extends beyond the 80-kilometer region.

Noninvolved (Surface) Workers

The analysis assumed noninvolved workers on the surface would be at the site 2,000 hours a year (8 hours a day, 5 days a week, 50 weeks a year), or about 23 percent of the total number of hours in a year (8,760). All surface workers, regardless of work responsibility, were considered to be noninvolved workers for evaluation of exposure to radon-222 and radon decay products released from the subsurface facilities. For releases of noble gases (principally krypton-85) from spent fuel handling activities, potentially exposed noninvolved workers would be all surface workers except those in the Waste Handling and Waste Treatment Buildings. The noble gases would be released from the Stack of the Waste Handling Building and workers in these facilities would not be exposed.

The maximally exposed noninvolved worker location for releases of radon and its decay products would be in the South Portal Development Area for all project phases. During the construction phase and development activities ventilation air from repository excavation activities would be exhausted through the South Portal, resulting in the highest potential exposure to radon and radon decay products. The analysis assumed that during these periods this worker would be in the office building about 100 meters (330 feet) northeast of the South Portal. This location is not directly in front of the South Portal but offset from what would be the ventilation plume centerline, so the atmospheric dispersion factor is reduced somewhat (see Section G.2.2). There would be no South Portal ventilation during monitoring activities and the closure phase, but the maximally exposed noninvolved worker would still be in the South Portal Development Area. For releases from the Waste Handling Building during spent fuel handling operations, the maximally exposed noninvolved worker location would be in the North Portal

Operations Area. When both surface and subsurface sources of radionuclides during operations are considered, the maximally exposed worker location would be the South Portal Development Area.

The population and distribution of repository workers required to staff the repository would depend on the specific parameters of the operating mode. The highest labor requirements listed in Table G-49 would be for the lower-temperature operating mode with spent fuel aging. The lowest labor requirements would be for the higher-temperature operating mode.

Table G-49. Noninvolved (surface) worker population distribution for Yucca Mountain air quality analyses.[a,b,c,d]

		Fulltime equivalent worker years	
		Operating mode	
Worker location	Time period	Higher-temperature	Lower-temperature
Construction phase	5 years		
North Portal		4,000	3,800 - 4,100
South Portal		490	490
Operation and monitoring			
Emplacement and development			
North Portal (exposure to subsurface releases)	24 or 50 years[e]	31,000	31,000 - 50,000
South Portal	24 years	1,500	1,600 - 2,100
North Portal (exposure to WHB/WTB releases)	24 years	8,200[d]	8,200 - 9,100[f]
Monitoring and maintenance			
North Portal – decontamination	3 years	3,400	2,800 - 3,400
North Portal – monitoring and maintenance	73 - 297 years	2,800	3,700 - 11,000
South Portal	76 - 300 years	930	1,200 - 3,700
Closure			
North Portal	6 years	4,000	4,000
South Portal	10 - 17 years	420	470 - 720
Retrieval[g]			
North Portal – construction	10 years	1,800	(h)
North Portal – operations	11 years	1,200	(h)
South Portal – operations	11 years	150	(h)

a. Sources: Appendix F, Table F-3 and DIRS 150941-CRWMS M&O (2000, p. 4-52).
b. Numbers are rounded to two significant figures.
c. Fifteen percent of fulltime equivalent subsurface worker time would be spent on the surface in the South Portal Development Area (based on DIRS 150941-CRWMS M&O (2000, p. 4-52).
d. Fulltime equivalent worker years for the time period listed.
e. 50 years for aging only.
f. Total workers exposed to krypton-85 releases from surface facilities. All noninvolved workers, does not include involved workers in Waste Handling or Waste Treatment Buildings; includes 15 percent of subsurface workers.
g. The retrieval period would last 14 years. There would be 3 years of initial construction followed by 7 additional years of construction during operations. Retrieval operations would last 11 years. Sources: DIRS 152010-CRWMS M&O (2000, pp. I-16 to I-20); DIRS 150941-CRWMS M&O (2000, pp. 6-19 to 6-20).
h. The retrieval contingency is not a part of the Proposed Action. Results are in Chapter 4, Section 4.2.1.2.2.

The estimated population of workers in the South Portal Development Area was based on the number of full-time equivalents of subsurface workers. This would include full-time South Portal Development Area workers as well as workers who would be on the surface for only a portion of a day as they prepared for underground work. The number of subsurface workers located in the South Portal Development Area was estimated to be 15 percent of the total subsurface workers. Also evaluated as a potentially exposed noninvolved worker population were DOE workers at the Nevada Test Site. The analysis used a Nevada Test Site worker population of 6,576 workers (DIRS 101811-DOE 1996, Volume I, Appendix A, p. A-69).

For purposes of analysis, all these workers were assumed to be about 50 kilometers (30 miles) east-southeast of the repository at Mercury, Nevada.

G.2.2 METEOROLOGICAL DATA AND ATMOSPHERIC DISPERSION FACTORS

The basis for the atmospheric dispersion factors used in the dose calculations was a joint frequency distribution file for 1993 to 1997. These data were based on site-specific meteorological measurements made at air quality and meteorology monitoring Site 1, combined for 1993 to 1997 (DIRS 102877-CRWMS M&O 1999, p. 11). Site 1 is about 1 kilometer (0.6 mile) south of the proposed North Portal surface facility location. Similar topographic exposure would lead to similar prevailing northerly and southerly winds at both locations. DOE used these data because an analysis of the data collected at all the sites showed Site 1 to be most representative of the surface facilities (DIRS 102877-CRWMS M&O 1999, p. 7). The joint frequency data are somewhat different from the more detailed meteorological data used for the nonradiological air quality analysis. The dose calculations required only annual average data because they compare doses to annual limits, whereas criteria pollutant limits have 1-, 3-, 8-, or 24-hour averaging periods and the calculation of short-term criteria pollutant concentrations required hourly meteorological data. The nonradiological analysis also calculated concentrations only at the land withdrawal area boundary, not at onsite locations where workers would be.

Depending on the operating mode, project phase, and level of activity, subsurface ventilation air could be exhausted from three to nine exhaust shafts and the South Portal. These exhaust shafts would be on the ridge above the repository. Table G-50 lists the distribution of exhaust ventilation air among the subsurface release points for the operating modes and project phases and activities. These distributions were used to calculate annual average atmospheric dispersion factors for radon releases from the subsurface.

The GENII software system (DIRS 103821-Napier et al. 1988, all) was used to calculate annual average atmospheric dispersion factors for radon released from the subsurface exhaust points and for noble gases released from the Waste Handling Building stack. The releases from the South Portal would be at ground level, while releases from the exhaust shafts on the ridge above the repository were modeled as 60-meter (200-foot) releases. Noble gas releases from the Waste Handling Building would be from a 60-meter (200-foot) stack, also modeled as an elevated release. Table G-51 lists the atmospheric dispersion factors for the radon and krypton-85 release points at the site that incorporate the release distribution data in Table G-50. The radon dispersion factors would vary among combinations of operating mode and project phase because of the differences in release point contributions noted in Table G-50. Population dispersion factors have been normalized to be independent of the population size. The population distribution data in Tables G-48 and G-49 can be used with the atmospheric dispersion factors to calculate population-weighted dispersion factors for public and noninvolved worker populations, from which collective doses can be calculated.

G.2.3 RADIOLOGICAL SOURCE TERMS

There would be two distinctly different types and sources of radionuclides released to the air from activities at the repository. Naturally occurring radon-222 and its radioactive decay products would be released from the subsurface facility during all phases as the repository ventilation system removed airborne particulates from development operations and exhausted air heated by the emplaced materials. Radioactive noble gases would be released from commercial spent nuclear fuel during handling and transfer operations in the surface facilities during the operation and monitoring phase. Section G.2.3.1 discusses the releases of radon-222 and radon decay products. Section G.2.3.2 discusses the releases of radioactive noble gases from commercial spent nuclear fuel.

Table G-50. Distribution (percent) of repository subsurface exhaust ventilation air.[a,b]

Operating mode, release point	Construction	Concurrent development and emplacement	Emplacement only; and monitoring	Closure
Proposed Action: higher-temperature				
South Portal	100	30	NA[c]	NA
Exhaust Shaft 1	NA	40	33.3	33.3
Exhaust Shaft 2	NA	20	33.3	33.3
Exhaust Shaft 3	NA	10	33.3	33.3
Proposed Action: lower- temperature maximum ventilation; Inventory Modules 1 and 2: higher-temperature				
South Portal	100	30	NA	NA
Exhaust Shaft 1	NA	20	16.7	16.7
Exhaust Shaft 2	NA	15	16.7	16.7
Exhaust Shaft 3	NA	10	16.7	16.7
Exhaust Shaft 4	NA	10	16.7	16.7
Exhaust Shaft 5	NA	10	16.7	16.7
Exhaust Shaft 6	NA	5	16.7	16.7
Proposed Action: lower-temperature maximum waste package spacing; Inventory Modules 1 and 2: lower-temperature operating mode				
South Portal	100	20	NA	NA
Exhaust Shaft 1	NA	10	11.1	11.1
Exhaust Shaft 2	NA	10	11.1	11.1
Exhaust Shaft 3	NA	10	11.1	11.1
Exhaust Shaft 4	NA	10	11.1	11.1
Exhaust Shaft 5	NA	10	11.1	11.1
Exhaust Shaft 6	NA	5	11.1	11.1
Exhaust Shaft L1	NA	10	11.1	11.1
Exhaust Shaft L2	NA	10	11.1	11.1
Exhaust Shaft L3	NA	5	11.1	11.1

a. Sources: Derived from DIRS 153849-DOE (2001, pp. 2-139 to 2-147); DIRS 155515-Williams (2001, Part 1, pp. 6 to 7, Part 2, pp. 5 to 6).
b. Exhaust shaft releases are elevated; portal releases are ground-level.
c. NA = not applicable.

G.2.3.1 Release of Radon-222 and Radon Decay Products from the Subsurface Facility

In the subsurface facility the noble gas radon-222 would diffuse continually from the rock into the air of the repository drifts. Radioactive decay of the radon in the air of the drift would produce radon decay products, which would begin to come into equilibrium (having the same activity) with the radon-222 because their radioactive half-lives are much shorter than the 3.8-day half-life of radon-222. Key radionuclide members of the radon-222 decay chain are polonium-218 and polonium-214, with half-lives of 3.05 minutes and 164 microseconds, respectively. Exhaust ventilation would carry the radon-222 and the radon decay products from the repository.

The estimates of radon-222 and its decay product releases were based on concentration observations made in the Exploratory Studies Facility subsurface areas during site characterization and subsequent analyses of these data (DIRS 150246-CRWMS M&O 2000, all; DIRS 154176-CRWMS M&O 2000, all). These two reports have significantly expanded the available information on radon-222 flux into the repository, radon concentrations in the repository, and radon release from the repository.

Table G-51. Atmospheric dispersion factors (seconds per cubic meter) for potentially exposed individuals and populations.[a,b,c]

Operating mode, receptor	Receptor location	Construction	Operation and monitoring: Concurrent development and emplacement	Operation and monitoring: Emplacement only; and monitoring	Closure
Repository radon releases					
Proposed Action, higher-temperature					
Public MEI[d]	(e)	2.2×10^{-8}	1.1×10^{-8}	6.0×10^{-9}	6.0×10^{-9}
Public population	80 km[f] radius	4.8×10^{-9}	2.3×10^{-9}	1.3×10^{-9}	1.3×10^{-9}
Worker MEI	South Portal	6.2×10^{-5}	1.9×10^{-5}	1.8×10^{-8}	1.8×10^{-8}
Worker population	South Portal	3.1×10^{-5}	9.3×10^{-6}	1.8×10^{-8}	1.8×10^{-8}
Worker population	North Portal	2.7×10^{-7}	8.9×10^{-8}	1.1×10^{-8}	1.1×10^{-8}
Nevada Test Site worker population	50 km east-southeast	6.9×10^{-10}	4.0×10^{-10}	2.7×10^{-10}	2.7×10^{-10}
Proposed Action: lower-temperature maximum ventilation; Inventory Modules 1 and 2: higher-temperature					
Public MEI	(e)	2.2×10^{-8}	1.1×10^{-8}	6.0×10^{-9}	6.0×10^{-9}
Public population	80 km radius	4.7×10^{-9}	2.3×10^{-9}	1.3×10^{-9}	1.3×10^{-9}
Worker MEI	South Portal	6.2×10^{-5}	1.9×10^{-5}	2.1×10^{-8}	2.1×10^{-8}
Worker population	South Portal	3.1×10^{-5}	9.3×10^{-6}	2.1×10^{-8}	2.1×10^{-8}
Worker population	North Portal	2.7×10^{-7}	9.0×10^{-8}	1.5×10^{-8}	1.5×10^{-8}
Nevada Test Site worker population	50 km east-southeast	6.9×10^{-10}	4.0×10^{-10}	2.7×10^{-10}	2.7×10^{-10}
Proposed Action: lower-temperature maximum waste package spacing; Inventory Modules 1 and 2: lower-temperature					
Public MEI	(e)	2.2×10^{-8}	9.2×10^{-9}	6.0×10^{-9}	6.0×10^{-9}
Public population	80 km radius	4.8×10^{-9}	2.0×10^{-9}	1.3×10^{-9}	1.3×10^{-9}
Worker MEI	South Portal	6.2×10^{-5}	1.2×10^{-5}	2.9×10^{-8}	2.9×10^{-8}
Worker population	South Portal	3.1×10^{-5}	6.2×10^{-6}	2.9×10^{-8}	2.9×10^{-8}
Worker population	North Portal	2.7×10^{-7}	6.9×10^{-8}	2.1×10^{-8}	2.1×10^{-8}
Nevada Test Site worker population	50 km east-southeast	6.9×10^{-10}	3.5×10^{-10}	2.7×10^{-10}	2.7×10^{-10}
Waste Handling Building stack releases				Operations	
Public MEI	(e)			6.0×10^{-9}	
Public population	80 km radius			1.3×10^{-9}	
Worker MEI	North Portal			3.2×10^{-7}	
Worker population	North Portal			3.2×10^{-7}	
Worker MEI	South Portal			6.4×10^{-8}	
Worker population	South Portal			6.4×10^{-8}	

a. Numbers are rounded to two significant figures.
b. Includes contribution and distribution from all operating exhaust shafts and portals. Stack and exhaust shaft releases would be elevated; south portal releases would be ground-level.
c. Dispersion factors have been normalized for populations. Multiply times the population to get the population dispersion factor.
d. MEI = maximally exposed individual.
e. Located at the southern boundary of the land withdrawal area.
f. km = kilometer; to convert kilometers to miles, multiply by 0.62137.

The radon-222 flux into the repository would depend on many different parameters. One such parameter is the repository air pressure, which would depend on the ventilation flow rate. Air pressure, radon flux, and radon concentration were estimated for the portion of the repository ventilated by one exhaust shaft for the higher-temperature repository operating mode (DIRS 154176-CRWMS M&O 2000, pp. 18 to 25). These characteristics were assumed to be applicable for each area of the repository ventilated by an exhaust shaft, so the higher-temperature operating mode—with three exhaust shafts—would have three areas with these exhaust characteristics. Similar assumptions were made for the lower-temperature operating mode where the repository would be ventilated by six to nine exhaust shafts. The analysis modeled a fully excavated, functioning repository, but these characteristics would be representative of all repository phases. This assumption might tend to overestimate the actual release of radon from the repository.

From the above information, average radon flux and radon release values were determined for three major types of repository excavation. The distinctions, which are based on the diameter of the excavation, include 7.6-meter (25-foot) and similar diameter excavations, typical of main drifts, ramps, and ventilation shafts; 5.5-meter (18-foot) and similar diameter excavations, typical of emplacement, standby, and observation drifts; and 2-meter (6.6-foot) and similar diameter excavations, typical of ventilation raises. The estimated average radon fluxes for these excavation types would be 35, 41, and 41 picocuries per square meter of exposed rock area per second, respectively. As noted above, these fluxes were assumed to apply to the respective diameter excavations in all repository areas. The estimated average activity of radon emanating per year per meter of the respective excavation types would be 0.021, 0.022, and 0.008 curie per meter per year. Information on the length and volume of repository excavations during the construction phase and during subsequent development is available for the range of operating modes analyzed (DIRS 150941-CRWMS M&O 2000, pp. 6-5 and 6-10; DIRS 155515-Williams 2001, Part 1, pp. 11 and 16, and Part 2, pp. 9 and 14). The analysis assumed that lengths and volumes would increase linearly over the project periods during which excavation took place, namely the 5 years of the construction phase and 22 years of development during the operations period at the beginning of the operation and monitoring phase.

The analysis assumed that, during the construction phase and development activities, all excavated areas of the repository except the 5.5-meter (18-foot) drifts (emplacement drifts, etc.) would be lined with concrete. This liner would be a barrier to radon diffusion into the repository, which would reduce radon flux by 50 percent (DIRS 152541-Ikenberry 2000, all). The analysis assumed the liners would be added linearly to applicable areas of the repository throughout the construction phase and the development period. The only exception would be a portion of the South Main Drift and ramp, which would not be lined with concrete until late in the development period. The analysis also assumed that the liners throughout the repository would be maintained during the preclosure period to prevent and seal fractures and maintain the reduction in radon flux for applicable repository areas.

Construction Phase

Repository excavation and radon releases would be very similar for the operating modes during the 5 years of the construction phase. The initial Exploratory Studies Facility excavated volume of about 420,000 cubic meters (550,000 cubic yards) would increase to 1.7 million to 2.1 million cubic meters (2.2 million to 2.7 million cubic yards) by the end of the construction phase. Most of the excavation during this phase would be for the 7.6-meter (25-foot) drifts and shafts.

Operation and Monitoring Phase

Operations Period. The operations period would last 24 years without aging, 50 years with aging. Development activities would take place during the first 22 years of operation and monitoring. During this period an additional 2.7 million to 6.8 million cubic meters (3.5 million to 8.9 million cubic yards) of repository volume would be excavated (DIRS 150941-CRWMS M&O 2000, p. 6-10; DIRS 155515-Williams 2001, Part 1, pp. 11 and 16 and Part 2, pp. 9 and 14). The total excavated volume would range from 4.3 million to 8.8 million cubic meters (5.6 million to 11.5 million cubic yards). During development activities a sizeable amount of the excavation would be of the 5.5-meter (18-foot) emplacement drifts and other 5.5-meter excavations. The maximum annual radon release would begin following the completion of

Table G-52 lists the estimated releases of radon-222 and radon decay products annually and by project phase.

Table G-52. Estimated radon-222 releases for repository activities under the Proposed Action.

Project phase or period and operating mode	Annual average radon release[b] (curies)	Maximum annual radon release[b,c] (curies)	Total radon release[b] (curies)	Duration (years)
Total, all phases				
Higher-temperature	1,900		220,000	115
Lower-temperature	1,400 - 4,100		480,000 - 1,000,000	171 - 341
Construction Phase				
Higher-temperature	480	610	2,400	5
Lower-temperature	480 - 570	610 - 750	2,400 - 2,900	5
Operations period				
Higher-temperature	1,500	2,100	36,000	24
Lower-temperature	2,100 - 3,800	3,000 - 4,600	50,000 - 190,000	24, 50
Monitoring period				
Higher-temperature	2,100	2,100	160,000	76
Lower-temperature	1,000 - 4,600	1,000 - 4,600	410,000 - 940,000	99 - 300
Closure phase				
Higher-temperature	1,500	2,100	15,000	10
Lower-temperature	2,000 - 2,800	2,900 - 4,500	22,000 - 48,000	11 - 17
Retrieval scenario				
Higher-temperature[d]	2,100		30,000	14

a. Numbers are rounded to two significant figures; totals might not equal sums of values due to rounding.
b. Includes radon-222 and radon decay products.
c. In general, these maximum annual values occur only for a single year. The major exception is for monitoring.
d. Retrieval is not part of the Proposed Action and only the higher-temperature operating mode was evaluated.

excavation, lasting the final 2 years (no aging) or 26 years (aging) of the operations period, and continue through the monitoring period. Highest annual average radon releases during operations would come from 6.4-meter (21-foot) waste package spacing of the lower-temperature operating mode, which would have the largest development and total excavated repository volume. Use of spent nuclear fuel aging would result in the highest operations period releases because of the additional 26 years of operations required.

Monitoring Period. No excavation would take place during the monitoring period, and the ventilation flowrate would remain constant, as would the radon release rate.

Monitoring and maintenance activities would last 76 years for the higher-temperature operating mode and up to 300 years of the lower-temperature operating mode. The highest total releases during monitoring would occur because of a 300-year monitoring period with forced ventilation. The lowest monitoring period release would occur if 250 years of natural ventilation were used following 50 years of forced ventilation. Releases during the monitoring period would account for 75 to 92 percent of the total radon released over the entire project duration.

Closure Phase

Annual releases of radon-222 and radon decay products during the closure phase would decrease linearly over the phase as the repository was gradually closed. The initial release rate would be the same as the monitoring period release rate and the ending release rate would equal that at the start of the operations period. The decrease in release rate from beginning to end would be 70 to 80 percent. Differences in the lengths of the closure phase (ranging from 10 to 17 years) would lead to additional differences in the total amount of radon released.

Retrieval

Only the higher-temperature repository operating mode was evaluated for a postulated retrieval scenario. Estimated releases would occur over a 14-year period of construction and retrieval operations. The 10-year planning period preceding retrieval was assumed to occur during the monitoring period and was not included in the evaluation. The annual release rate of radon-222 and its decay products would be the same as that for the monitoring period.

Inventory Modules 1 and 2

Releases of radon-222 and its decay products for Inventory Modules 1 and 2 were estimated using the same methods as those used for the Proposed Action. The major differences would be the larger repository volumes, which would result in larger releases of radon. In addition, the project duration would be longer under the Proposed Action, with 38 years required to complete operations (which would include 36 years of development), and a longer closure phase. Table G-53 lists estimated radon releases. Releases of radon would be higher for the inventory modules than for the Proposed Action in all cases.

Table G-53. Estimated radon-222 releases for repository activities for Inventory Modules 1 or 2.[a]

Project phase and operating mode	Annual average radon release[b] (curies)	Maximum annual radon release[b,c] (curies)	Total radon release[b] (curies)	Duration (years)
Total, all phases				
Higher-temperature	2,600		300,000	117
Lower-temperature	2,100 - 6,200		760,000 - 1,600,000	191 - 359
Construction phase				
Higher-temperature	480	610	2,400	5
Lower-temperature	560 - 570	730 - 750	2,800 - 2,900	5
Operations period				
Higher-temperature	2,000	3,200	78,000	38
Lower-temperature	2,800 - 5,100	4,500 - 7,400	110,000 - 260,000	38 or 51
Monitoring period				
Higher-temperature	3,200	3,200	200,000	62
Lower-temperature	1,500 - 7,400	1,500 - 7,400	610,000 - 1,400,000	112 - 300
Closure phase				
Higher-temperature	2,100	3,100	25,000	12
Lower-temperature	2,800 - 4,300	4,400 - 7,300	44,000 - 98,000	15 - 23

a. Numbers are rounded to two significant figures; totals might not equal sums of values due to rounding.
b. Includes radon-222 and radon decay products.
c. In general these maximum annual values would occur only for a single year. The major exception would be for monitoring.

G.2.3.2 Release of Radioactive Noble Gases from the Surface Facility

The unloading and handling of commercial spent nuclear fuel would produce the only routine emissions of manmade radioactive materials from repository facilities. No releases would occur as a result of emplacement activities. Shipping casks containing spent nuclear fuel would be opened in the transfer pool of the Waste Handling Building at the North Portal Operations Area. During spent nuclear fuel handling and transfer, radionuclides could be released from a small percentage of fuel elements with pinhole leaks in the fuel cladding; only noble gases would escape the pool and enter the ventilation system of the Waste Handling Building (DIRS 104508-CRWMS M&O 1999, p. 17). The largest release of radionuclides from surface facilities would be krypton-85, with about 2,600 curies released annually. Releases of other noble gas radionuclides would be very small, with estimated annual releases of about 0.0000010 curie of krypton-81, 0.000033 curie of radon-219, 0.059 curie of radon-220, 0.0000046 curie of radon-222, and even smaller (negligible) quantities of xenon-127 (DIRS 152010-CRWMS M&O 2000, p. 52). The same annual releases would occur for both the Proposed Action and for the inventory modules. Of these radionuclides, krypton-85 would be by far the largest and most important dose contributor, from releases totaling 61,000 curies for the Proposed Action and 97,000 curies for the inventory modules. All spent nuclear fuel and high-level radioactive waste in disposable canisters would be transferred from shipping casks to disposal containers in shielded rooms (hot cells) in the Waste Handling Building. Because all DOE material would be in sealed disposable canisters, no radionuclide releases from these materials would occur.

Releases of noble gases from the surface facility would be the same for all operating modes. These estimated releases were based on the following assumptions for commercial spent nuclear fuel (DIRS 104508-CRWMS M&O 1999, p. 17):

- Pressurized-water reactor burnup of about 40 gigawatt-days per metric ton of uranium with 3.7-percent enrichment and an average of 26 years decay
- Boiling-water reactor burnup of 32 gigawatt-days per metric ton of uranium with 3-percent enrichment and an average of 27 years decay
- A failure rate of 0.25 percent for fuel assemblies in the canisters, allowing gaseous radionuclides (isotopes of krypton, radon, and xenon) to escape
- Radionuclides other than noble gases (such as cobalt-60, cesium-137, and strontium-90) would not escape the transfer pool if released from fuel assemblies

G.2.3.3 Release from Waste Packages Prior to Repository Closure

DOE examined the potential for release of radionuclides from failed waste packages and failed spent nuclear fuel during the operation and monitoring phase and the closure phase to determine if this would be another source of manmade radionuclides during the repository project.

DOE considered the potential for failure of waste packages and spent nuclear fuel cladding in detail in evaluating the long-term performance of the repository (see Chapter 5 and Appendix I). Section 5.5.1 notes that more than 99 percent of the cladding on spent nuclear fuel would be intact at the time it was placed in waste packages and emplaced in the repository. Appendix I, Section I.2.4, discusses the early failure of waste packages, and notes that a small number of waste packages (zero to three) could undergo early failure caused by improper heat treatment of the outer lid closure weld. This analysis is conservative and does not account for the inner lid weld or the inner barrier lid weld. For preclosure activities, it is assumed that the inner lid and the inner barrier lid welds are in place. Therefore, no releases from waste packages during the preclosure period are expected.

G.2.4 DOSE CALCULATION METHODOLOGY

The previous three sections provided information on the location and distribution of potentially affected individuals and populations (Section G.2.1), atmospheric dispersion (Section G.2.2), and the type and quantity of radionuclides released to air (Section G.2.3) in the Yucca Mountain region. The analysis used these three types of information to estimate the radionuclide concentration in air (in picocuries of radionuclide per liter of air) at a specific location or for an area where there would be a potentially exposed population. The estimation of the radiation dose to exposed individuals or populations from concentrations of radionuclides in air used this information and published dose factors. This section describes the concentration-to-dose conversion factors that the analysis used to estimate radiation dose to members of the public and noninvolved workers from releases of radionuclides at the repository.

G.2.4.1 Dose to the Public

The analysis estimated doses to members of the public using screening dose factors from the National Council on Radiation Protection and Measurements (DIRS 101882-NCRP 1996, Volume I, pp. 113 and 125). Use of these factors results in a conservative (tending to overestimate) estimate of the dose that could be received). The analysis considered all exposure pathways, including inhalation, ingestion, and direct external radiation from radionuclides in the air and on the ground. For noble gases released from the Waste Handling Building, krypton-85 would be by far the most important and largest dose contributor. Only direct external exposure from radionuclides in the air would be a contributing exposure pathway. The analysis estimated the dose from krypton-85 by multiplying 1) the radionuclide activity released 2) the atmospheric dispersion factor at the exposure location and 3) the radionuclide-specific dose factor, with appropriate unit conversions (for example, seconds per year or liters per cubic meter) included. Table G-54 lists the screening dose factor for krypton-85 for members of the public. The analysis assumed that members of the public would be exposed for 8,000 hours per year (DIRS 101882-NCRP 1996, Volume I, p. 61). Results are presented in Chapter 4, Section 4.1.2.

Table G-54. Factors for estimating dose to the public and noninvolved workers per concentration of radionuclide in air (millirem per picocurie per liter per hour) for krypton-85 and radon-222.[a,b]

Radionuclide	Public	Noninvolved worker
Krypton-85[c]	0.0000013	0.0000013
Radon-222[d]	0.25[e]	0.00091[f]

a. Numbers are rounded to two significant figures.
b. Dose factors for radon-222 include dose contribution from decay products.
c. Source: DIRS 101882-NCRP (1996, p. 113); normalized from exposure time of 8,000 hours per year (p. 61).
d. Source: DIRS 101882-NCRP (1996, p. 125); normalized from exposure time of 8,000 hours per year (ground exposure is one-fourth of total exposure) (p. 61).
e. Includes all exposure pathways.
f. Includes only the inhalation and plume exposure pathways.

The short-lived decay products of radon-222 would account for essentially the entire dose from radon and its decay products, and the degree to which the decay products would reach equilibrium with radon-222 and their total activity are important considerations. At release from the repository, the estimated average fraction of equilibrium reached would be 0.22 (DIRS 154176-CRWMS M&O 2000, attachment 4), or 22 percent of the radon-222 activity. Once released to the atmosphere, the decay product activity would begin to build toward equilibrium with the parent radon-222 activity with a halftime of about one-half hour. It is difficult to estimate the equilibrium fraction in this dynamic outdoor environment. A typical outdoor radon equilibrium level is 60 percent (DIRS 155699-NCRP 1984, p. 25), with a lower degree of equilibrium closer to the source. Although this value is for a continuous radon source emanating from the ground over an essentially infinite area, DOE used it as a conservative estimate of the equilibrium fraction. The analysis used the average annual wind speed of 2.5 to 4.4 meters per second (5.6 to 9.8 miles per hour) (see Chapter 3, Section 3.1.2.2) to estimate the radon decay product equilibrium fraction at the location of members of the public. It used 3 meters per second (6.7 miles per hour) as representative. The transit time to the location of the maximally exposed individual at the southern boundary of the land withdrawal area would be less than 2 hours (0.08 day). At this location the estimated equilibrium fraction would be 0.5, so the radon decay product activity would be 50 percent of the radon released, with these radionuclides available to enter the exposure pathways. For the population within 80 kilometers (50 miles), the estimated equilibrium fraction would be 0.6, and the radon decay product activity would be 60 percent of the radon released, with these radionuclides available to enter the exposure pathways. These estimates do not include removal mechanisms such as the deposition of radon decay products, so they are conservative, tending to overestimate the actual dose that could be received.

The screening dose factors for radon-222 and its decay products indicate that direct external radiation from radionuclides deposited on the ground would account for about 40 percent of the dose. Ingestion of the radon decay products in foodstuffs and inadvertently consumed soil would account for about 60 percent of the dose. Inhalation and external irradiation from radionuclides in the air would be minor exposure pathways. The analysis estimated the dose from radon-222 and its decay products by multiplying the radon-222 activity released by the equilibrium factor by the atmospheric dispersion factor at the exposure location by the radionuclide-specific dose factor, with appropriate unit conversions included. Table G-54 lists the screening dose factors for radon-222 and its decay products for members of the public. Results are presented in Chapter 4, Section 4.1.2.

Dose to members of the public (and to noninvolved workers, described below) is calculated in the following manner using the information presented throughout Section G.2:

$$\text{dose (millirem per year)} = Q \times \chi/Q \times F \times DF \times t \times \text{(unit conversion factors)}$$

where Q = activity released (curies per year)

χ/Q = atmospheric dispersion factor (seconds per cubic meter)

F = equilibrium fraction for radon decay products at exposure location (unitless)

DF = dose factor from Table G-54

t = exposure time, in hours per year

Unit conversion factors used include liters per cubic meter, picocuries per curies, and seconds per year. Multiplying the activity release by the atmospheric dispersion factor by the equilibrium fraction, if applicable—with appropriate unit conversions—yields the radionuclide concentration in air at the point of exposure.

G.2.4.2 Dose to Noninvolved Workers

The analysis used the same krypton-85 screening dose factor described above to calculate doses to noninvolved workers because the exposure pathway is simple (air submersion only) and is the same as for members of the public. However, the radon-222 screening dose factor for involved workers is different from that used for the public, because noninvolved workers are exposed only through the inhalation and plume exposure pathways. The other exposure pathways are not applicable for noninvolved workers, namely the ground exposure and ingestion pathways. The ground exposure pathway was not included because site workers would not typically be in locations where decay products could build up for many years without being physically disturbed or washed away.

Section G.2.1 describes the location of the maximally exposed noninvolved worker in the South Portal Development Area. There would be no releases from the South Portal during the other project phases and atmospheric dispersion factors would be much smaller (greater dispersion and, therefore, lower resulting radiation dose). The estimated equilibrium fraction for Yucca Mountain noninvolved worker exposure would be 0.22, the same as that for ventilation air at the exhaust point, as described in Section G.2.4.1. Transit times from release to a noninvolved worker or noninvolved worker population would be short, ranging from less than 1 minute to about 30 minutes at wind speeds of 3 meters per second (6.7 miles per hour), and deposition of radon decay products would occur, so the increase toward equilibrium would be small. The estimated equilibrium fraction for noninvolved workers at the Nevada Test Site would be 0.5, because the transit time of about 5 hours (0.19 day) for the 50-kilometer (31-mile) distance would allow the radon decay products to reach a higher level of equilibrium.

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Note: In an effort to ensure consistency among Yucca Mountain Project documents, DOE has altered the format of the references and some of the citations in the text in this Final EIS from those in the Draft EIS. The following list contains notes where applicable for references cited differently in the Draft EIS.

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